

TR-1421
SOME THEORETICAL NOTES
ON THE DETACHABLE-LEVER ESCAPEMENT

December 1963



U.S. ARMY MATERIALS COMMAND

HARRY DIAMOND LABORATORIES
WASHINGTON, D. C. 20318

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**SOME THEORETICAL NOTES
ON THE DETACHED-LEVER ESCAPEMENT**

by
David R. Haley

December 1968



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HARRY DIAMOND LABORATORIES
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ABSTRACT

This report presents a continuation of the first detailed mathematical analysis made on a detached-lever escapement timing device. The model studied was based on the T5K1 pin-lever escapement, designed primarily for ordnance applications. Although good quantitative results evolved from the original study, subsequent work suggested that the model was not capable of simulating certain characteristics of the detached-lever escapement. For example, this type escapement often had a torque sensitivity characteristic (frequency vs driving torque) that was concave upward.

Further mathematical analysis has resulted in minor but apparently significant changes to the original model, indicating the feasibility of predicting the performance of an escapement more accurately. Also, this analysis—though probably incomplete—now indicates that certain basic characteristics of timers can be changed without changing the basic mechanism.

CONTENTS

	Page No.
ABSTRACT.....	3
1. INTRODUCTION.....	7
2. ESCAPEMENT.....	7
2.1 Equations of Motion.....	7
2.2 Modifications to Equations of Motion.....	10
2.3 Method of Solution.....	17
2.4 Escape Wheel Torque T_e	20
3. ELEMENTARY PARAMETRIC STUDIES USING ESCAPEMENT MODEL.....	20
3.1 Side-Thrust Effects.....	20
3.2 Variation in Coefficient of Friction During Unlocking.....	21
3.3 Variations in Pallet-Lever Inertia and Escape-Wheel Inertia.....	22
3.4 Effect of Ratio D/R ₁	22
3.5 The Angle β^*	22
3.6 Escape Wheel to Pallet-Lever Center Distance.....	23
3.7 Escape-Wheel Tooth Geometry.....	23
3.8 Hairspring and Balance Inertia Studies.....	24
4. DISCUSSION AND CONCLUSIONS.....	24
APPENDIX A	50 - 54
APPENDIX B.....	55 - 117
DISTRIBUTION.....	119-123

ILLUSTRATIONS

Figure

1. Pin-lever escapement.....	26
2. Experimental and theoretical beat rate curves for TSE1 escapement.....	27
3. Diagrams showing events during forward half-cycle.....	28
4. Escapement geometry.....	29
5-24. Theoretical beat rate curves for TSE1 escapement.....	30-49
A-1 Sample BALCYC deck format.....	51

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1. INTRODUCTION

Under HDL contract DA-49-146-AMC-176(D), Minnix¹ derived the first detailed mathematical analysis of a detached-lever escapement timing device (fig. 1). The work reported herein is intended to expand that analysis to a more useful model.

Although Minnix used the TSEL pin-lever escapement as his model, his analysis was generalized to the extent of requiring only minor modifications to describe jewelled lever, folded lever, attached lever, and torsional oscillator escapements. That analysis was programmed for digital solution on an IBM 1620 computer, with numerical results that indicated the feasibility of predicting the escapement performance with an accuracy theretofore unattainable.

Despite that good quantitative results were obtained from the Minnix analysis, prior work by Overman and Bettwy² exhibited empirical characteristics of the detached-lever escapement that were not simulated with the model studied. HDL's experimental results show that this type of escapement may have a torque sensitivity curve (beat rate versus main-spring torque) that is concave upward. Note curve (a) in figure 2, which plots data on a TSEL escapement; also note that the Minnix model¹ shows a definite increase in beat rate as illustrated by curve (b) in figure 2.

An expansion of the Minnix analysis was therefore begun at HDL, which lead to some minor but apparently significant changes to the original model. These changes have been incorporated into a digital computer program (appx A & B) at these laboratories, based on the original analysis. The results of the further analysis are encouraging, in that (1) the performance of an escapement can be predicted with greater accuracy and (2) certain basic characteristics of timers can be changed without changing the basic mechanism.

2. ESCAPEMENT

2.1 Equations of Motion

The motion cycle of a detached lever escapement is divided into 12 phases, illustrated schematically for the "forward" half cycle in figure 3. Here, β represents displacement of the balance, measured positive counterclockwise and taken to be zero when the impulse pin

¹ Minnix R. B., "The Development of a Mathematical Model of the Detached Lever Escapement," Virginia Military Institute Research Laboratory, 1968.

² Overman, D. L. and Bettwy, D. S., "Experimental Mechanical Timer with Detached Lever Escapement and Digital Readout System," HDL Tech Memo 65-44, 1965.

lies on the line of centers of the balance and lever staff; β , the lever displacement, is measured positive counterclockwise, and taken to be $\pi/2$ (fig. 4) when $\beta = 0$; and the escape wheel displacement ϵ , is measured positive clockwise from an arbitrary initial line. The event not shown in figure 3 is the fifth in the sequence, in which the pallet lever is locked by the escape wheel while the balance is at an intermediate position. The catchup phase occurs between the time when unlocking ends and the pallet pin reengages the escape wheel tooth.

Several major assumptions were made by Minnix in his derivation of the equations of motion, both to simplify the analysis and to determine which of the many parameters involved in the design of the escapement are germane to its performance. Many of the original assumptions have been weeded from the model; those remaining that appear to be of greatest relevance are included below.

- (1) An effective geometry is defined so that
 - (a) pallet pins and impulse pins have zero diameter,
 - (b) there is no draw angle on the escape wheel teeth,
 - (c) there is no lever fork, and
 - (d) unlocking ends when $\beta = 0$;
- (2) The balance equilibrium position is at $\beta = 0$, that is, it is here that the hairspring exerts no torque;
- (3) The hairspring is linear (has a linear force-deflection curve);
- (4) Collisions are instantaneous and perfectly elastic;
- (5) Friction due to gravity at all pivots is negligible;
- (6) The energy transmission from escape wheel to balance during impulse incurs no losses.

It is in order to achieve (1 d) that certain other modifications to the geometry are assumed as described by Minnix (ch 3).¹

Under these assumptions, the following equations of motion for the balance are derived, assuming $\beta = \beta_m > 0$, $\dot{\beta} = 0$ at $t = 0$. This assumption obviously has no effect on the motion; it is made for convenience in describing the motion of the various phases. For a detailed derivation of these equations, see description by Minnix (ch 5) or appx A.

Free Motion: $\beta_1 \leq \beta \leq \beta_m$.

$$I_B \ddot{\beta} + (K-L)\beta = 0. \quad (1)$$

Here

I_B is the inertia of the balance,

1. Minnix, R. B., op. cit.

K is the hairspring deflection constant,
 L is a friction loss term due to the "side thrust" effect of the
hairspring.

Unlocking: $\beta_2 = 0 < \beta < \beta_1$.

$$I_1 \ddot{\beta} + \frac{1}{2} I_1 \dot{\beta} + (K-L)\beta = T_f. \quad (2)$$

Here $I_1 = I_B + X^2 I_L$,

I_L is the inertia of the pallet,

X is the lever arm ratio between balance and pallet lever,

T_f is the frictional torque in the negative sense arising from
the drag of the entrance pallet pin on the locking face of the escape
wheel tooth.

Catchup: $\beta_3 < \beta < \beta_2 = 0$.

$$I_1 \ddot{\beta} + \frac{1}{2} I_1 \dot{\beta} + (K+L)\beta = 0, \quad (3)$$

$$I_E \ddot{\epsilon} = -T_a. \quad (4)$$

Here

I_E is escape wheel inertia, and

T_a is applied torque at escape wheel.

Note that since the equations are independent during this phase, and
since (3) seems analytically intractable, we must rely on an iterative
procedure to determine β_3 .

Impulse: $\beta_4 < \beta < \beta_3$.

$$I_2 \ddot{\beta} + \frac{1}{2} I_2 \dot{\beta} + (K+L)\beta = XZT_a. \quad (5)$$

Here

$$I_2 = I_B + X^2 I_L + X^2 Z^2 I_E, \text{ and}$$

Z is the lever arm ratio between escape wheel and pallet lever.

Free Motion: $\beta_0 \leq \beta \leq \beta_4$.

$$I_B \ddot{\beta} + (K+L)\beta = 0. \quad (6)$$

Of the assumptions involved in the derivation of these equations, we shall accept all but the last part of the first and the second. A detailed study of the effect of the second part of the first assumption, the fifth, and the sixth will be reported in a subsequent paper.

2.2 Modifications to Equations of Motion

Consider the second assumption—that the hairspring exerts no torque on the balance when $\beta = 0$. This seems to be the design aim of all escapements of this type. But a cursory examination of even a rather large escapement indicates that the attainment in practice of such a goal is probably tedious. Thus the effect of variation of the equilibrium position is studied parametrically.

Assume that the hairspring exerts no torque on the balance staff when $\beta = \beta^*$. β^* is then known as the angle by which the escapement is "out of beat." The equations of motion then become:

Free Motion: $\beta_1 \leq \beta \leq \beta_m$.

$$I_B \ddot{\beta} + (K-L)(\beta-\beta^*) = 0. \quad (7)$$

Unlocking: $\beta_2 \leq \beta \leq \beta_1$.

$$I_1 \ddot{\beta} + \frac{1}{2} I_1 \dot{\beta} + (K-L)(\beta-\beta^*) = T_f \quad (8)$$

Catchup: $\beta_3 \leq \beta \leq \beta_2$.

$$I_1 \ddot{\beta} + \frac{1}{2} I_1 \dot{\beta} + (K+L)(\beta-\beta^*) = 0, \quad (9)$$

$$I_E \ddot{\epsilon} = -T_a.$$

Impulse: $\beta_4 \leq \beta \leq \beta_3$.

$$I_2 \ddot{\beta} + \frac{1}{2} I_2 \dot{\beta} + (K+L)(\beta-\beta^*) = XZT_a \quad (10)$$

Free Motion: $\beta_0 \leq \beta \leq \beta_4$.

$$I_B \ddot{\beta} + (K+I) (\beta - \beta^*) = 0. \quad (11)$$

If $\beta^* = 0$, these equations reduce to the previous equations of motion.

It will be shown subsequently that the timekeeping characteristics of an escapement are rather sensitive to changes in β^* .

As is explained in chapter 3 of reference 1, to achieve the assumption of unlocking at $\beta = \beta_2 = 0$, an "effective geometry" is defined with virtually all geometric parameters modified slightly to an "effective" value. The definitions of geometric parameters are to be found in figure 4. We define the effective value of each parameter as its actual value with the following exceptions. The notation is that of Minnix.

$$R_{pp} = 0. \quad (12)$$

$$R_{ee} = R_e + R_{pp}, \quad (13)$$

$$R_{2e} = R_2 + R_{pp} \quad (14)$$

We now follow Minnix's analysis exactly except to note that at unlocking $\beta = \beta_2 \neq 0$; but β_2 is now computed just as the other values, by using the relation between β and θ , θ_2 being known geometrically.

We have

$$\theta_2 = \cos^{-1} \left(\frac{R_e^2 + S^2 - R_{2e}^2}{2R_e S} \right) \quad (15)$$

and

$$\beta_2 = \sin^{-1} \left(\frac{D}{R_I} \sin \left(\frac{P}{2} - \theta_2 \right) \right) - \left(\frac{P}{2} - \theta_2 \right), \quad (16)$$

exactly the same formulae as before but geometrically more accurate due to the change in the effective geometry.

Similarly, by the symmetry of the pallet lever cycle,

$$\theta_4 = P - \theta_2 \quad (17)$$

and

$$\beta_0 = \sin^{-1} \left\{ \frac{D}{R_I} \sin \left(\frac{P}{2} - \theta_4 \right) \right\} - \left(\frac{P}{2} - \theta_4 \right). \quad (18)$$

To define the motion of the escapement subject to these equations, we must also recompute the initial velocities for each phase. We make use of the conservation of energy laws and the assumption of instantaneous, completely elastic collisions (thus conserving momentum).

Phase 1: The initial energy in this phase is entirely stored in the hairspring and the only dissipative effect is that of side thrust friction. Hence, equating energy at each end of the phase,

$$\begin{aligned} \frac{1}{2} K (\beta_m - \beta^*)^2 &= \frac{1}{2} K (\beta_1 - \beta^*)^2 + \frac{1}{2} I_B \dot{\beta}_{1b}^2 \\ + \int_{\beta_1}^{\beta_m} L(\beta - \beta^*) d\beta &= \frac{1}{2} K (\beta_1 - \beta^*)^2 + \frac{1}{2} I_B \dot{\beta}_{1b}^2 \\ + \frac{1}{2} L \left[(\beta_m - \beta^*)^2 - (\beta_1 - \beta^*)^2 \right], \end{aligned} \quad (19)$$

so that

$$\dot{\beta}_{1b}^2 = \frac{K-L}{I_B} \left[(\beta_m - \beta^*)^2 - (\beta_1 - \beta^*)^2 \right]. \quad (20)$$

The notation used here is followed throughout. Namely, when a collision occurs at balance amplitude β_j , $\dot{\beta}_{jb}$ denotes the balance velocity at the instant before collision, $\dot{\beta}_{ja}$ the balance velocity at the instant after collision. Also, we denote by I_{ij} the value of the coupled variable inertia I_i when $\beta = \beta_j$. For example, $I_{27} = I_2 \{\beta_7\}$.

Phase 2: By the assumption of an instantaneous and perfectly elastic collision at the beginning of unlocking, we have, by conservation of momentum,

$$I_B \dot{\beta}_{1b} = I_{11} \dot{\beta}_{1a},$$

so that

$$\dot{\beta}_{1a} = \frac{I_B}{I_{11}} \dot{\beta}_{1b} = \frac{-I_B}{I_{11}} \left\{ \frac{K-L}{I_B} \left[(\beta_m - \beta^*)^2 - (\beta_1 - \beta^*)^2 \right] \right\}^{\frac{1}{2}} \quad (21)$$

During this phase, energy is lost due to side-thrust friction and unlocking friction. Thus,

$$\begin{aligned} \frac{1}{2} K (\beta_1 - \beta^*)^2 + \frac{1}{2} I_{11} \dot{\beta}_{1a}^2 &= \frac{1}{2} I_{12} \dot{\beta}_2^2 \\ + \frac{1}{2} K (\beta_2 - \beta^*)^2 + \int_{\beta_2}^{\beta_1} L(\beta - \beta^*) d\beta + \int_{\beta_2}^{\beta_1} T_f d\beta. \end{aligned} \quad (22)$$

Minnix¹ (appx C) has exhibited a function U such that

$$T_f = T_f(\beta) = \mu T_a U(\beta).$$

For convenience, we define

$$I_U = \int_{\beta_2}^{\beta_1} U(\beta) d\beta. \quad (23)$$

Then (22) becomes

$$\begin{aligned} \frac{1}{2} K (\beta_1 - \beta^*)^2 + \frac{1}{2} I_{11} \dot{\beta}_{1a}^2 &= \frac{1}{2} I_{12} \dot{\beta}_2^2 + \frac{1}{2} K (\beta_2 - \beta^*)^2 \\ &+ \frac{1}{2} L \left[(\beta_1 - \beta^*)^2 - (\beta_2 - \beta^*)^2 \right] + \mu T_a I_U, \end{aligned} \quad (24)$$

so that

$$\dot{\beta}_2^2 = \frac{1}{I_{12}} \left\{ (K - L) [(\beta_1 - \beta^*)^2 - (\beta_2 - \beta^*)^2] + I_{11} \dot{\beta}_{1a}^2 - 2\mu T_a I_U \right\}.$$

Phase 3: Once $\dot{\beta}_2$ is known, β_3 can be found by the method described in the next section (2.3).

After this, expressions for $\dot{\beta}_{3b}$ and $\dot{\beta}_{3a}$ can be derived. Assume that $\beta_4 \leq \beta^* \leq \beta_2$.

In phase 3, only the side-thrust effect dissipates energy, so conservation laws guarantee that

$$\begin{aligned} \frac{1}{2} I_{12} \dot{\beta}_2^2 + \frac{1}{2} K (\beta_2 - \beta^*)^2 &= \frac{1}{2} K (\beta_3 - \beta^*)^2 + \frac{1}{2} I_{13} \dot{\beta}_{3b}^2 + \int_{\beta_3}^{\beta_2} L |\beta - \beta^*| d\beta \\ &= \frac{1}{2} K (\beta_3 - \beta^*)^2 + \frac{1}{2} I_{13} \dot{\beta}_{3b}^2 + \frac{1}{2} L \left[(\beta_2 - \beta^*)^2 - \text{sgn}(\beta_3 - \beta^*) (\beta_3 - \beta^*)^2 \right], \end{aligned} \quad (26)$$

so that

$$\dot{\beta}_{3b}^2 = \frac{1}{I_{13}} \left\{ I_{12} \dot{\beta}_2^2 + K [(\beta_2 - \beta^*)^2 - (\beta_3 - \beta^*)^2] - L (\beta_3 - \beta^*)^2 \right. \\ \left. - \text{sgn}(\beta_3 - \beta^*) (\beta_3 - \beta^*)^2 \right\} \quad (27)$$

Phase 4: As before, by assuming instantaneous and elastic collisions from conservation of momentum

$$\dot{\beta}_{3a} = (I_{13} \dot{\beta}_{3b} + X_3 Z_3 I_E \dot{\epsilon}_{3b}) / I_{23} \quad (28)$$

¹Minnix, R. B., op. cit.

Here $X_3 = X(\beta_3)$, $Z_3 = Z(\beta_3)$. During this phase, energy is carried away by side thrust losses and added to the system through impulse. Hence,

$$\begin{aligned} \frac{1}{2} K(\beta_3 - \beta^*)^2 + \frac{1}{2} I_{23} \dot{\beta}_3^2 a &= \frac{1}{2} K(\beta_4 - \beta^*)^2 \\ + \frac{1}{2} I_{24} \dot{\beta}_4^2 + \int_{\beta_4}^{\beta_3} L |\beta - \beta^*| d\beta + \int_{\beta_4}^{\beta_3} (-T_a) X Z d\beta. \end{aligned} \quad (29)$$

(The torque is applied opposed to ϵ .) Now, $Z = \frac{d\epsilon}{d\beta}$ in this half cycle, so

$$\int_{\beta_4}^{\beta_3} X Z d\beta = \epsilon_3 - \epsilon_4. \quad (30)$$

Further,

$$\int_{\beta_4}^{\beta_3} L |\beta - \beta^*| d\beta = \frac{1}{2} L \left[\operatorname{sgn}(\beta_3 - \beta^*) (\beta_3 - \beta^*)^2 + (\beta_4 - \beta^*)^2 \right] \quad (31)$$

Hence, (29) becomes

$$\begin{aligned} \frac{1}{2} K(\beta_3 - \beta^*)^2 + \frac{1}{2} I_{23} \dot{\beta}_3^2 a &= \frac{1}{2} K(\beta_4 - \beta^*)^2 + \frac{1}{2} I_{24} \dot{\beta}_4^2 \\ + \frac{1}{2} L \left[(\beta_4 - \beta^*)^2 + \operatorname{sgn}(\beta_3 - \beta^*) (\beta_3 - \beta^*)^2 \right] + T_a (\epsilon_4 - \epsilon_3). \end{aligned} \quad (32)$$

Solving for $\dot{\beta}_4^2$, we have

$$\begin{aligned} \dot{\beta}_4^2 &= \frac{1}{I_{24}} \left[I_{23} \dot{\beta}_3^2 a + K \left[(\beta_3 - \beta^*)^2 - (\beta_4 - \beta^*)^2 \right] \right. \\ &\quad \left. - L \left[(\beta_4 - \beta^*)^2 + \operatorname{sgn}(\beta_3 - \beta^*) (\beta_3 - \beta^*)^2 \right] + 2T_a (\epsilon_3 - \epsilon_4) \right] \quad (33) \end{aligned}$$

Phases 5 and 6: Here, only side-thrust friction induces losses. The equation of energy balance is

$$\begin{aligned} \frac{1}{2} K(\beta_4 - \beta^*)^2 + \frac{1}{2} I_{24} \dot{\beta}_4^2 &= \frac{1}{2} K(\beta_6 - \beta^*)^2 - \int_{\beta_6}^{\beta_4} L(\beta - \beta^*) d\beta \\ &= \frac{1}{2} K(\beta_6 - \beta^*)^2 - \frac{1}{2} L \left[(\beta_4 - \beta^*)^2 - (\beta_6 - \beta^*)^2 \right], \end{aligned} \quad (34)$$

implying

$$(\beta_6 - \beta^*)^2 = (\beta_4 - \beta^*)^2 + \frac{I_{24} \dot{\beta}_4^2}{K + L}. \quad (35)$$

Phase 7: As only side-thrust phenomena affect the energy balance, it follows that

$$\begin{aligned}\frac{1}{2} K (\beta_e - \beta^*)^2 &= \frac{1}{2} K (\beta_\gamma - \beta^*)^2 + \frac{1}{2} I_B \dot{\beta}_{\gamma b}^2 - \int_{\beta_\gamma}^{\beta_e} L(\beta - \beta^*) d\beta \\ &= \frac{1}{2} K (\beta_\gamma - \beta^*)^2 + \frac{1}{2} I_B \dot{\beta}_{\gamma b}^2 - \frac{1}{2} L \left[(\beta_\gamma - \beta^*)^2 - (\beta_e - \beta^*)^2 \right],\end{aligned}\quad (36)$$

or

$$\dot{\beta}_{\gamma b}^2 = \frac{K-L}{I_B} \left\{ (\beta_e - \beta^*)^2 - (\beta_\gamma - \beta^*)^2 \right\}. \quad (37)$$

Phase 8: By conservation of momentum,

$$I_{17} \dot{\beta}_{\gamma a} = I_B \dot{\beta}_{\gamma b},$$

or, noting $I_{17} = I_{11}$,

$$\dot{\beta}_{\gamma a} = \frac{I_B}{I_{11}} \left\{ \frac{K-L}{I_B} \left[(\beta_e - \beta^*)^2 - (\beta_\gamma - \beta^*)^2 \right] \right\}^{\frac{1}{2}} \quad (38)$$

Applying conservation of energy principles and noting losses and contributions of energy,

$$\begin{aligned}\frac{1}{2} K (\beta_\gamma - \beta^*)^2 + \frac{1}{2} I_{17} \dot{\beta}_{\gamma a}^2 &= \frac{1}{2} I_{18} \dot{\beta}_e^2 + \frac{1}{2} K (\beta_e - \beta^*)^2 \\ - \int_{\beta_\gamma}^{\beta_e} L(\beta - \beta^*) d\beta - \int_{\beta_\gamma}^{\beta_e} T_f d\beta &= \frac{1}{2} I_{18} \dot{\beta}_e^2 + \frac{1}{2} K (\beta_e - \beta^*)^2 \\ - \frac{1}{2} L \left[(\beta_e - \beta^*)^2 - (\beta_\gamma - \beta^*)^2 \right] + \mu I_U T_a,\end{aligned}\quad (39)$$

implying

$$\dot{\beta}_e^2 = \frac{1}{I_{18}} \left\{ (K-L) \left[(\beta_\gamma - \beta^*)^2 - (\beta_e - \beta^*)^2 \right] - 2\mu I_U T_a + I_{17} \dot{\beta}_{\gamma a}^2 \right\}. \quad (40)$$

Phase 9: By the principles used in the eight previous phases, it may be concluded that

$$\begin{aligned}\frac{1}{2} I_{18} \dot{\beta}_e^2 + \frac{1}{2} K (\beta_e - \beta^*)^2 &= \frac{1}{2} K (\beta_e - \beta^*)^2 + \frac{1}{2} I_{18} \dot{\beta}_{\gamma b}^2 \\ + \int_{\beta_e}^{\beta_\gamma} L |\beta - \beta^*| d\beta &= \frac{1}{2} K (\beta_e - \beta^*)^2 + \frac{1}{2} I_{18} \dot{\beta}_{\gamma b}^2 \\ + \frac{1}{2} L \left[(\beta_e - \beta^*)^2 + \operatorname{sgn} (\beta_e - \beta^*) (\beta_e - \beta^*)^2 \right].\end{aligned}\quad (41)$$

Therefore,

$$\dot{\beta}_{eb} = \frac{1}{I_{1e}} \left\{ I_{1e} \dot{\beta}_{ea}^2 + K \left[(\beta_e - \beta^*)^2 - (\beta_{1e} - \beta^*)^2 \right] - L \left[(\beta_e - \beta^*)^2 + \text{sgn}(\beta_e - \beta^*) (\beta_e - \beta^*)^2 \right] \right\}. \quad (42)$$

Phase 10: By the usual methods,

$$\dot{\beta}_{ea} = \frac{1}{I_{2e}} \left\{ I_{1e} \dot{\beta}_{eb} - X_e Z_e I_E \dot{\epsilon}_{eb} \right\}. \quad (43)$$

Looking at the energy balance,

$$\begin{aligned} \frac{1}{2} K (\beta_e - \beta^*)^2 + \frac{1}{2} I_{2e} \dot{\beta}_{ea}^2 &= \frac{1}{2} K (\beta_{10} - \beta^*)^2 + \frac{1}{2} I_{2,10} \dot{\beta}_{10}^2 \\ &+ \int_{\beta_e}^{\beta_{10}} L |\beta - \beta^*| d\beta - \int_{\beta_e}^{\beta_{10}} X Z T_a d\beta. \end{aligned} \quad (44)$$

But in this half cycle, since $XZ = - \frac{d\epsilon}{d\beta}$, we have

$$\int_{\beta_e}^{\beta_{10}} X Z T_a d\beta = -T_a (\epsilon_e - \epsilon_{10}); \quad (45)$$

further,

$$\int_{\beta_e}^{\beta_{10}} L |\beta - \beta^*| d\beta = \frac{1}{2} L \left[(\beta_{10} - \beta^*) - \text{sgn}(\beta_e - \beta^*) (\beta_e - \beta^*)^2 \right]. \quad (46)$$

Therefore, (44) becomes

$$\begin{aligned} \frac{1}{2} K (\beta_e - \beta^*)^2 + \frac{1}{2} I_{2e} \dot{\beta}_{ea}^2 &= \frac{1}{2} K (\beta_{10} - \beta^*)^2 + \frac{1}{2} I_{2,10} \dot{\beta}_{10}^2 \\ &+ \frac{1}{2} L \left[(\beta_{10} - \beta^*)^2 - \text{sgn}(\beta_e - \beta^*) (\beta_e - \beta^*)^2 \right] + T_a (\epsilon_e - \epsilon_{10}), \end{aligned} \quad (47)$$

which yields

$$\begin{aligned} \dot{\beta}_{10}^2 &= \frac{1}{I_{2,10}} \left\{ I_{2e} \dot{\beta}_{ea}^2 + K \left[(\beta_e - \beta^*)^2 - (\beta_{10} - \beta^*)^2 \right] \right. \\ &\quad \left. - L \left[(\beta_{10} - \beta^*)^2 - \text{sgn}(\beta_e - \beta^*) (\beta_e - \beta^*)^2 \right] - 2T_a (\epsilon_e - \epsilon_{10}) \right\}. \end{aligned} \quad (48)$$

Phases 11 and 12: By use of another equilibrium condition, the following simpler expression can be obtained for $\dot{\beta}_{10}^2$.

$$\begin{aligned} \frac{1}{2} K (\beta_{10} - \beta^*)^2 + \frac{1}{2} I_B \dot{\beta}_{10}^2 &= \frac{1}{2} K (\beta_m - \beta^*)^2 + \int_{\beta_{10}}^{\beta_m} L(\beta - \beta^*) d\beta \\ &= \frac{1}{2} K (\beta_m - \beta^*)^2 + \frac{1}{2} L \left[(\beta_m - \beta^*)^2 - (\beta_{10} - \beta^*)^2 \right], \end{aligned} \quad (49)$$

so

$$\dot{\beta}_{10}^2 = \frac{K+L}{I_B} \left[(\beta_m - \beta^*)^2 - (\beta_{10} - \beta^*)^2 \right] \quad (50)$$

and we have all the necessary initial conditions.

2.3 Method of Solution

Since the displacement β of the balance is not explicitly desired as a function of time, we solve for the time expended in each phase. To do this, regardless of the apparent diversity of equations of motion, only three general forms need be considered. This approach is due primarily to Bloom.¹

In phases 1, 5, 6, 7, 11, and 12, the equation of motion is of the form

$$\ddot{I}\beta + c(\beta - \beta^*) = 0,$$

the harmonic oscillator equation, readily solved explicitly.

In phases 2, 4, 8, 10, the equation can be written in the form

$$\ddot{I}(\beta)\ddot{\beta} + \frac{1}{2} \dot{I}(\beta)\dot{\beta} + c(\beta - \beta^*) = F(\beta) \quad (51)$$

Let $v = \dot{\beta}$ and denote by a prime, differentiation with respect to β (that is, $\frac{df}{d\beta} = f'$).

Then

$$\ddot{\beta} = v \frac{dv}{d\beta} = vv'$$

¹ Calculations derived by H. M. Bloom, KDL staff member, on a detached lever escapement system (1968).

and (51) becomes

$$Ivv' + \frac{1}{2} v^2 I' + c(\beta - \beta^*) = F(\beta). \quad (52)$$

Upon the substitution $g = v^2$, so that $g' = 2vv'$, (52) reduces to

$$\frac{1}{2} Ig' + \frac{1}{2} I'g + c(\beta - \beta^*) = F(\beta), \quad (53)$$

or

$$(Ig)' = 2(F(\beta) - c(\beta - \beta^*)). \quad (54)$$

For the given phase under consideration, let β_0 and β denote the initial and final balance displacements. Then, integrating (54) to a given displacement, we have

$$\int_{\beta_0}^{\beta} \frac{d}{d\xi} ((I(\xi)g(\xi))d\xi = 2 \int_{\beta_0}^{\beta} [F(\xi) - c(\xi - \beta^*)] d\xi, \quad (55)$$

or

$$I(\beta)g(\beta) = I(\beta_0)g(\beta_0) + 2 \int_{\beta_0}^{\beta} F(\xi)d\xi + c[(\beta_0 - \beta^*)^2 - (\beta - \beta^*)^2]. \quad (56)$$

Define

$$H(\beta) = 2 \int_{\beta_0}^{\beta} F(\xi)d\xi, \quad (57)$$

and

$$C_0 = I(\beta_0)g(\beta_0) + c(\beta_0 - \beta^*)^2. \quad (58)$$

Now we have

$$g(\beta) = v^2(\beta) = \dot{\beta}^2 = \frac{1}{I(\beta)} [H(\beta) - c(\beta - \beta^*)^2 + C_0]. \quad (59)$$

Thus,

$$\frac{d\beta}{dt} = \pm \left\{ \frac{1}{I(\beta)} [H(\beta) - c(\beta - \beta^*)^2 + C_0] \right\}^{\frac{1}{2}}. \quad (60)$$

The apparent ambiguity of sign does not in fact exist, for $\dot{\beta} \leq 0$ in phases 1-6 and $\dot{\beta} \geq 0$ in phases 7-12. For typographical convenience,

we now consider only the positive root. Separating variables and integrating, we have, if t_0 and t_f denote initial and final times for the phase,

$$t_f - t_0 = \int_{t_0}^{t_f} dt = \int_{t_0}^{t_f} \frac{\sqrt{I(\xi)} \dot{\xi} dt}{\sqrt{H(\xi) + C(\xi - \beta^*)^2 + C_0}}$$

$$= \int_{\beta_0}^{\beta_f} \frac{\sqrt{I(\xi)} d\xi}{\sqrt{H(\xi) + C(\xi - \beta^*)^2 + C_0}}. \quad (61)$$

The integral on the right in (61) can be evaluated easily by standard quadrature techniques. Thus, the problem is solved for these phases.

The analysis for phases 3 and 9 proceeds in much the same way, in that after noting $F(\beta) \equiv 0$, we have

$$t_f - t_0 = \int_{\beta_0}^{\beta_f} \left[\frac{I(\xi)}{C(\xi - \beta^*)^2 + C_0} \right]^{\frac{1}{2}} d\xi. \quad (62)$$

In this case, however, we do not know β_f ($= \beta_3$ or β_9); but we can solve for β_f and t_f simultaneously by an iterative procedure. In these phases the escape wheel turns freely under the influence of the mainspring torque alone, as described by

$$\frac{I}{E} \ddot{\epsilon} = -T_a,$$

or

$$\epsilon(t) = \epsilon_0 - \left(\frac{T_a}{2I_E} \right) t^2, \quad (63)$$

where

$$\epsilon(t_0) = \epsilon_0,$$

$$\dot{\epsilon}(t_0) = 0.$$

We also have (Minnix, ch 4)¹ a coupling equation of the form

$$\epsilon(\beta) = f_{\epsilon}(\beta),$$

valid when the pallet pin and escape wheel tooth are in contact. Using these equations, it is possible to iterate to a solution for the desired quantities.

¹ Minnix, R. B., op. cit.

2.4 Escape Wheel Torque T_a

The assumption that the escape wheel torque T_a is constant was made because we are interested only in equilibrium conditions. A major objective of this study is to determine what changes the beat rate of an escapement, thus rendering the mechanism inaccurate. It is clear that, apart from transient conditions, beat rate at constant torque must be constant. Hence, by assuming T_a to be constant, we can find the corresponding steady-state beat rate and thus determine the way this rate varies with torque.

3. ELEMENTARY PARAMETRIC STUDIES USING ESCAPEMENT MODEL

An elementary study was made next of the effect on the escapement's performance of the variation of several geometric and dynamic parameters of its design. Since constancy of beat rate is of prime importance for a good mechanism, we shall look at the changes effected in the plot of beat rate versus escape wheel torque.

Most of the ensuing beat rate curves will have end points corresponding to balance amplitudes of 60 and 330 deg, with corresponding range of escape-wheel torques lying generally between 200 and 14,000 dyne-cm. It is believed that under normal operating conditions, the mainspring of the T5E1 escapement supplies a torque at the escape wheel of between 1000 and 6000 dyne-cm.

3.1 Side-Thrust Effects

Shinkle¹ seems to have first noted that, in addition to exerting a torque on the balance staff, the hairspring of an escapement must also exert a "side-thrust" force perpendicular to the staff with the resulting friction acting to oppose balance motion.

To assume that the magnitude of this frictional torque is linearly dependent on balance displacement is consistent with the assumption of hairspring linearity, as is the assumption that the torque is zero when $\beta=\beta^*$.

Minnix, in some of his early work with Overman, determined that the coefficient of side-thrust friction should have the value $L=13.83$ dyne-cm/radian for the T5E1 escapement. This was an empirical determination and its accuracy is unknown.

¹Shinkle, J. M., "Detached Lever Escapement Study," Sandia Corp Report SC-RR-65-57 (1965).

The plots in figure 5 show, as has been observed by Shinkle, that beat rate is markedly dependent upon this coefficient. This may be somewhat surprising at first in view of the ratio of L to the spring constant K ($K=921.9$ dyne-cm/radian for the T5E1). But an examination of the various energy losses incurred by the escapement shows that side-thrust losses constitute one of the major loss mechanisms.

Notice should be taken of the type of change in the beat-rate curve brought about by a change in L . Primarily, as L grows larger, the beat rate curve shifts downward and higher torque is required to drive the escapement at a given balance amplitude, the downward shift being more pronounced at lower torques (amplitudes). A characteristic, which is readily observed here and can be seen to permeate all of the curves presented herein, is that all the curves seem to be asymptotic at high torques to a curve qualitatively rather similar to a log-log plot. This phenomenon will become even clearer in later figures.

It can be noted that a hairspring can never really have a side-thrust coefficient of zero. However, it is also clear that the use of a torsion wire as balance spring would correspond to $L=0$. Thus, figure 5 lends credence to the thesis that a torsional oscillator should make an excellent timing mechanism.

3.2 Variation in Coefficient of Friction During Unlocking

In most ways, side-thrust losses are quite similar to other frictional losses. And indeed, L can be derived as a function of balance staff geometry and the coefficient of friction, μ , which was not done in this study.

Since the coefficient of friction varies widely among different surfaces and materials, it is almost meaningless to talk of a nominal value. The actual value can be determined only by experimentation. But it is meaningful and informative to study, as in the previous section, the effect of changes in μ during the unlocking phase (see eq 22) on timekeeping characteristics. Figure 6 shows that the results are quite similar to those exhibited in figure 5, as might be expected.

It will be shown later that once μ and L are known, certain geometric parameters can be varied to counteract the effect of lower beat rate at lower torque. Indeed, it will be shown that we can flatten the curve considerably in the middle and toward the right, and raise it essentially as high as desired on the left, thus generating a curve quite flat overall.

3.3 Variations in Pallet-Lever Inertia and Escape-Wheel Inertia

It is deemed that the graphs representing parametric variations in beat rate for changes in pallet lever and escape wheel inertias (fig. 7 and 8, respectively) are self-explanatory and represent nothing except that which might be expected—that a "heavier" mechanism runs more slowly. The similarity of these curves to those generated in frictional studies (fig. 5 and 6) seems rather remarkable.

3.4 Effect of Ratio D/R_I

The first of the geometric parameters are considered next. The distance D from balance staff center to pallet staff center and the impulse radius R_I are not considered separately, but only their ratio since it is only this ratio that enters into the analytical formulation of the model.

Of the quantities examined, this ratio seems to be the least critical to escapement performance. This seems a little surprising, not only because all other geometry seems quite significant, but this ratio determines in large part the lever arm for energy transmission from mainspring to balance. Figure 9 shows just how insensitive the mechanism is to variations in D/R_I.

3.5 The Angle β^*

As mentioned, it is only natural to study the response of a mechanism to changes in β^* . In such a study, some quite interesting phenomena are to be observed, as seen in figure 10 for the nominal T5EL configuration. Here, as before, β^* denotes the hairspring equilibrium position.

First, as β^* increases, so does the beat rate for any given torque—that is, the whole curve shifts up or down with β^* . Second, as β^* increases, the beat rate curve attains a greater positive slope for balance amplitudes of about 90 deg or less ($T_b \approx 600$ dyne/cm). Third, and perhaps most important, as β^* increases, a large middle segment of the beat rate curve rises faster than the rest, thus destroying the nominal curve shape and monotonicity and generating a beat rate that may even decrease with increasing torque.

Note particularly that for $\beta^* = 2$ deg, the beat rate changes by less than 0.02 bps for escape wheel torques between 900 and 9000 dyne-cm. This represents a maximum deviation of about 0.04 percent over the normal operating range.

Also important here is that the asymptotic tendency of the beat rate curve is still present for high torques, even though we have shown how to change the basic shape of the plot.

3.6 Escape Wheel to Pallet-Lever Center Distance

Another geometric parameter S , the distance from escape-wheel staff center to pallet-lever staff center, is seen from figure 11 to have some considerable effect on the mechanism's torque sensitivity.

Three points about figure 11 seem worthy of mention. First, changes in S are seen to effect only rather slight changes in beat rate for high torques (amplitudes). Second, the family of curves tails off sharply at low torques as S decreases. Third and most salient, as S is increased past about 0.2400 in., the beat rate continues to increase at low torques; the beat rate actually decreases at higher torques, causing distinct curves within the family to intersect. Nothing even remotely suggesting that this phenomenon might occur has been observed elsewhere.

Noting the curves in figures 10 and 11, one might conjecture that if, say, $S=0.2420$ and $\beta^* = 1$ deg, a quite flat beat rate curve might be generated. That such is the case may be noted from figure 12.

3.7 Escape-Wheel Tooth Geometry

It might be expected that the shape of the escape wheel teeth would have a greater effect on the performance of an escapement than any other design parameter. This turns out to be hardly the case.

Recall from figure 4 the definitions of the radii R_1 and R_2 and the face angle γ . We shall leave the central angle defining the tooth unchanged so that, for a given value of the root radius R_e , any two of the quantities R_1 , R_2 , and γ define the tooth completely. For the nominal T5E1 escapement, these quantities take on the values:

$$R_1 = 0.184 \text{ in.},$$

$$R_2 = 0.2019 \text{ in.}, \text{ and}$$

$$\gamma = 50 \text{ deg}$$

In figure 13, we see the effect of holding R_2 constant while γ varies and R_1 is changed dependently; no really significant change is effected. But in figure 14, R_1 is held constant, varying R_2 and γ and causing some noticeable torque sensitivity at the lower end.

It seems worthwhile to emphasize again the asymptotic tendency exhibited in figures 13 and 14.

3.8 Hairspring and Balance Inertia Studies

Since a mechanical escapement is essentially a linear oscillator of known natural frequency with some energy input to compensate for various losses, twice this natural frequency is a rather good approximation to the beat rate of the mechanisms. However, as shown, beat rate tends to vary with escape-wheel torque. In order to study how this torque sensitivity varies with beat rate, appropriate mechanisms were examined with the escapement model; the results are presented in figures 15 through 23.

Two points seem noteworthy here. First, for a given spring, it is seen that the higher inertia balances tend to yield less torque-sensitive designs. That is to say, the beat-rate curves are flatter. And second, the curve in figure 23 seems to have been obtained from the nominal curve (see fig. 24) by a shift to the right along itself, away from the steeper low torque area, thus tending to flatten the curve. The difference between the two mechanisms is that the hairspring constant, balance inertia, and side-thrust coefficient have each been doubled.

In figures 15-23, the natural beat rate of the balance is plotted for comparison and is labeled ω_n . It seems from these plots that the horizontal line corresponding to this natural beat rate is the asymptote mentioned previously.

4. DISCUSSION AND CONCLUSIONS

Assuming that our escapement model yields accurate results, the design of timing movements may be transferred from the domain of skilled craftsmen to an engineering atmosphere, at least for ordnance applications. We have discovered some of the design parameters to changes in which torque sensitivity seems very dependent; and there are some that seem to have little effect on this sensitivity. Use of this information and a little jiggling of computer cards, can yield the beat-rate curve presented in figure 24 very nearly flat, with no basic change to the T5E1 escapement. Apparently, under certain conditions, simple basic modifications to the T5E1 might predict even better results. For example, a stronger spring might be used to run the escapement at higher torques, thus moving the operating region to the flatter portion of the beat-rate curve.

But the model is incomplete and the validity of its predictions is really unknown. There are several obvious changes and additions

that need to be effected, including:

- (1) Provision for consideration of the escape tooth draw angle;
- (2) Capability to consider friction at the balance and pallet-lever pivots;
- (3) Provision for friction between pallet pin and escape-wheel tooth during impulse; and
- (4) Inclusion of lever fork geometry.

Although this report discusses the sensitivity of performance to changes in certain design parameters, no design changes are given for removing such sensitivities. And it would be in this area that this analysis would have its greatest value, allowing manufacturing tolerances to be relaxed and, hopefully, permitting the design of rugged, inexpensive, yet accurate timers. It is indicated, however, that the analysis in its present form is sufficient to determine, qualitatively at least, the effect of parameter variations throughout manufacturing tolerance ranges. As such, it should provide a valuable tool in setting such tolerances.

Assuming that a first step has been taken toward a means of transferring escapement design ability and responsibility from the artisan to the engineer, it is suggested that the following three additional steps are necessary to effect this transfer:

- (1) Incorporate into the model the further refinements mentioned above;
- (2) Initiate an extensive experimental program to determine the accuracy of the model; and,
- (3) Conduct a detailed study of the energy analysis derived by Minnix to devise methods of eliminating the undesirable characteristics discovered. For instance, is it possible to design a mechanism insensitive to side-thrust losses? Or to changes in S (fig 4)? Or to escape tooth geometry?

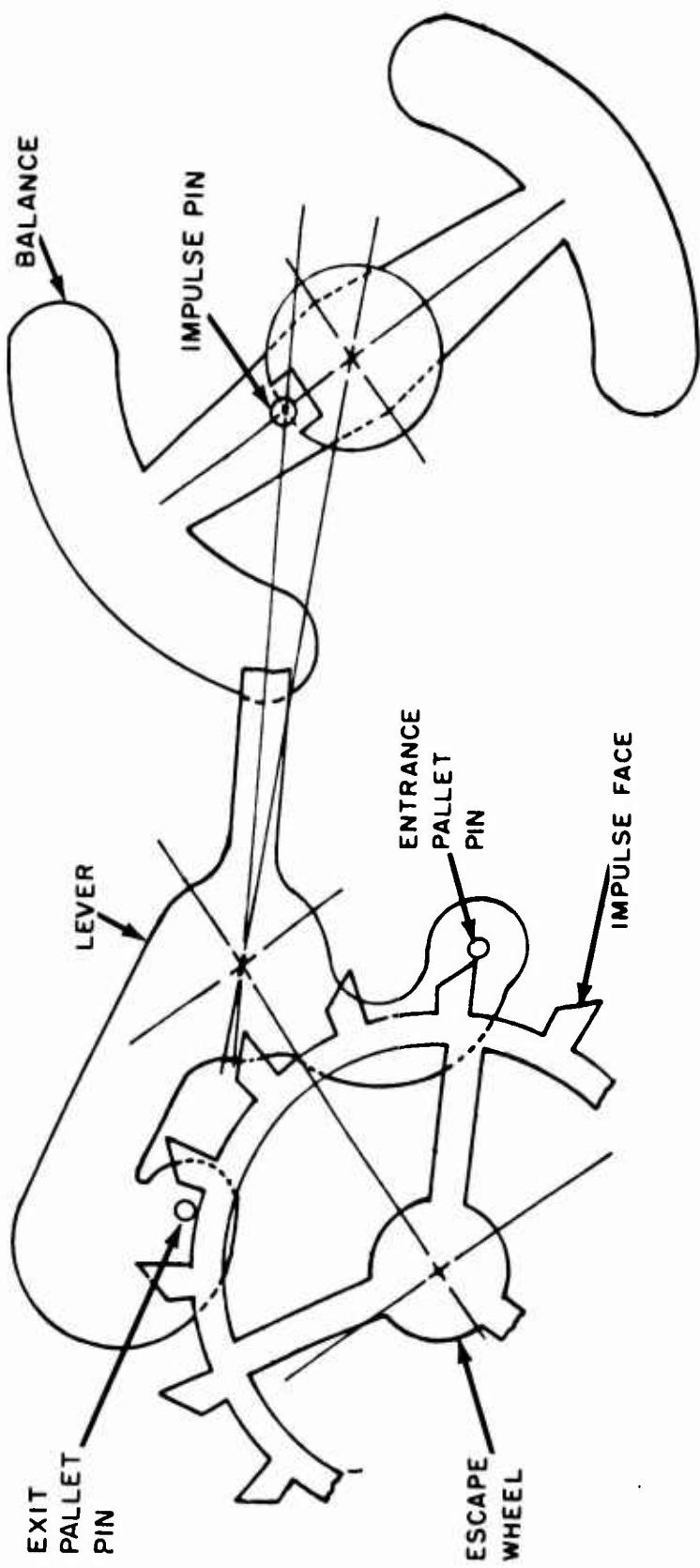


Figure 1. Pin-lever escapement.

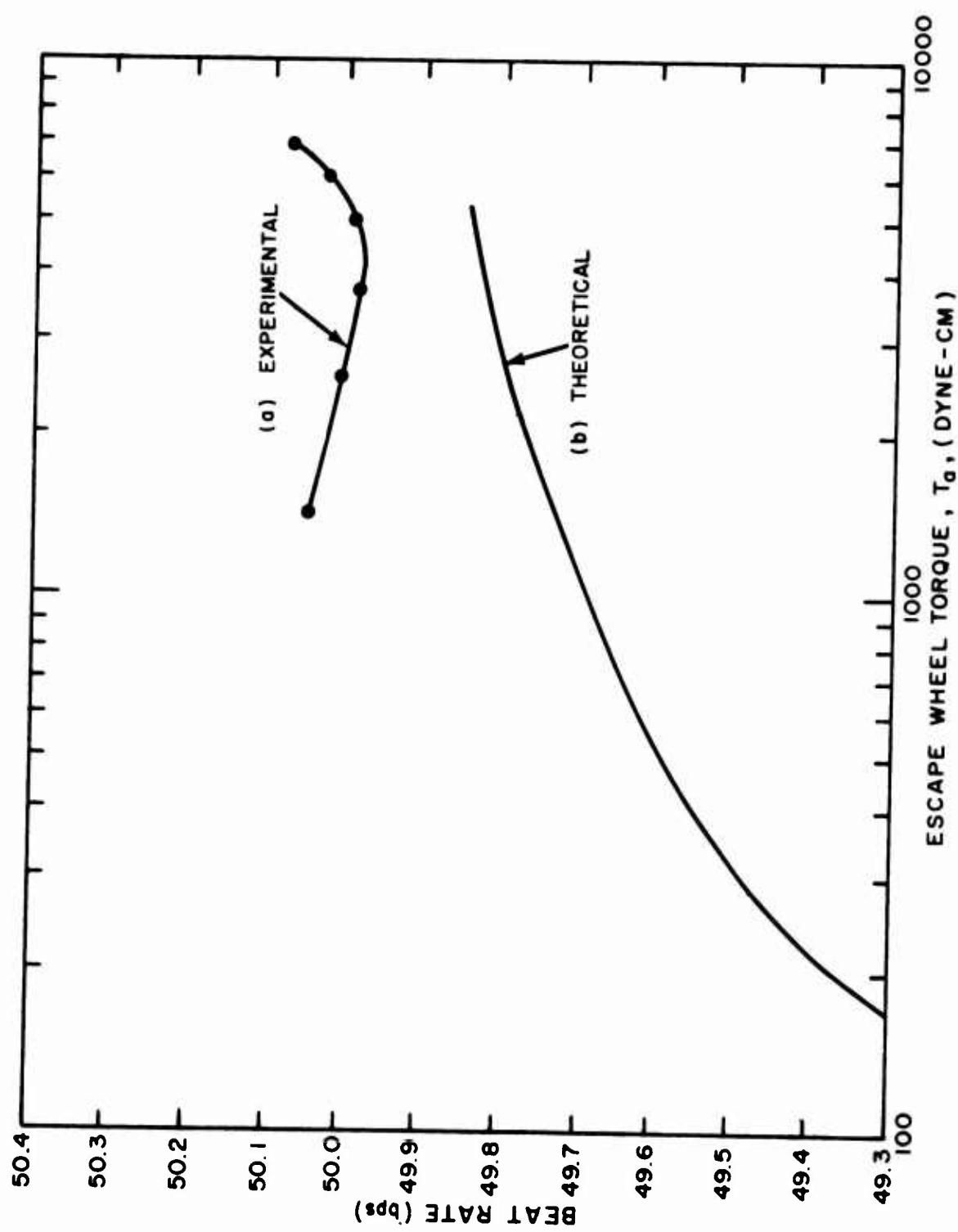


Figure 2. Experimental and theoretical beat rate curves for T5E1 escapement.

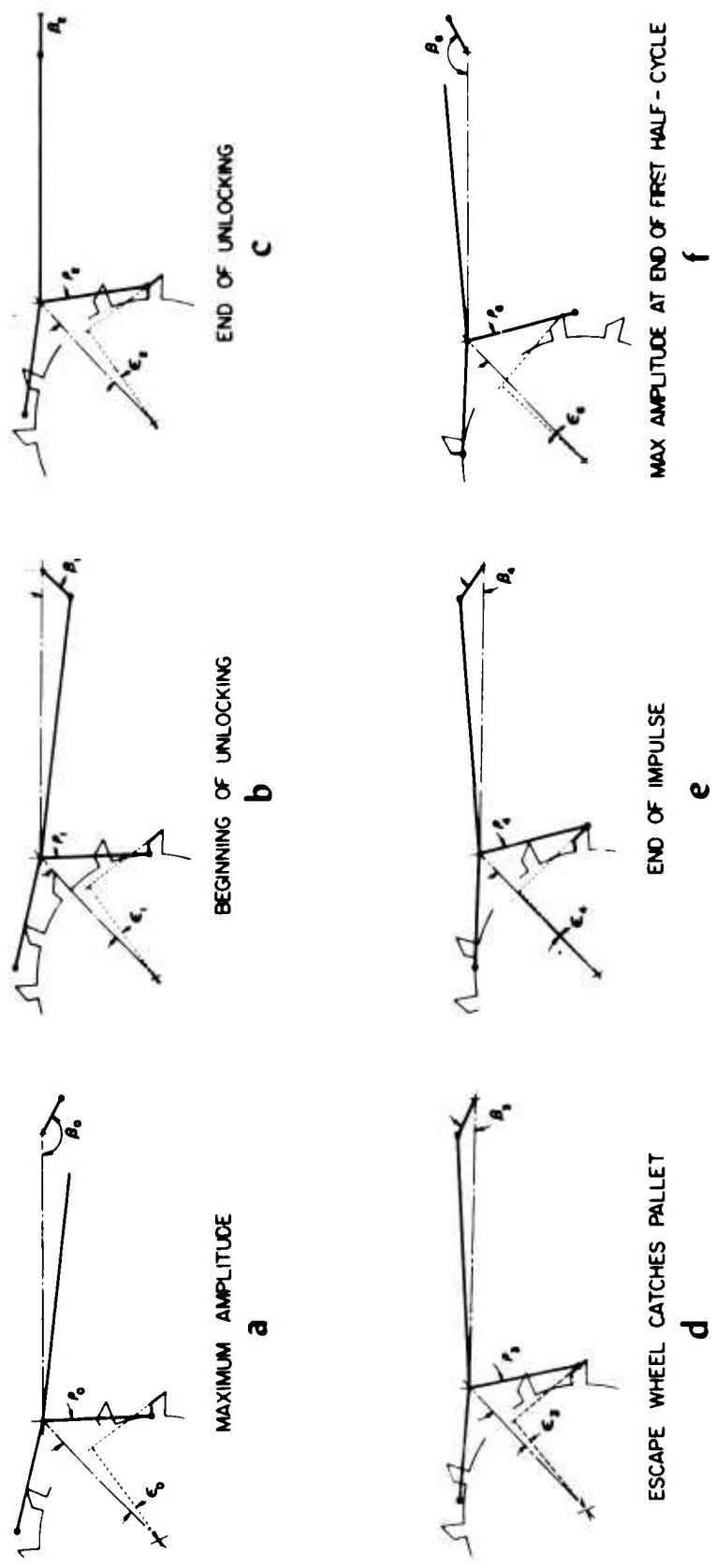


Figure 3. Diagrams showing events during forward half-cycle.

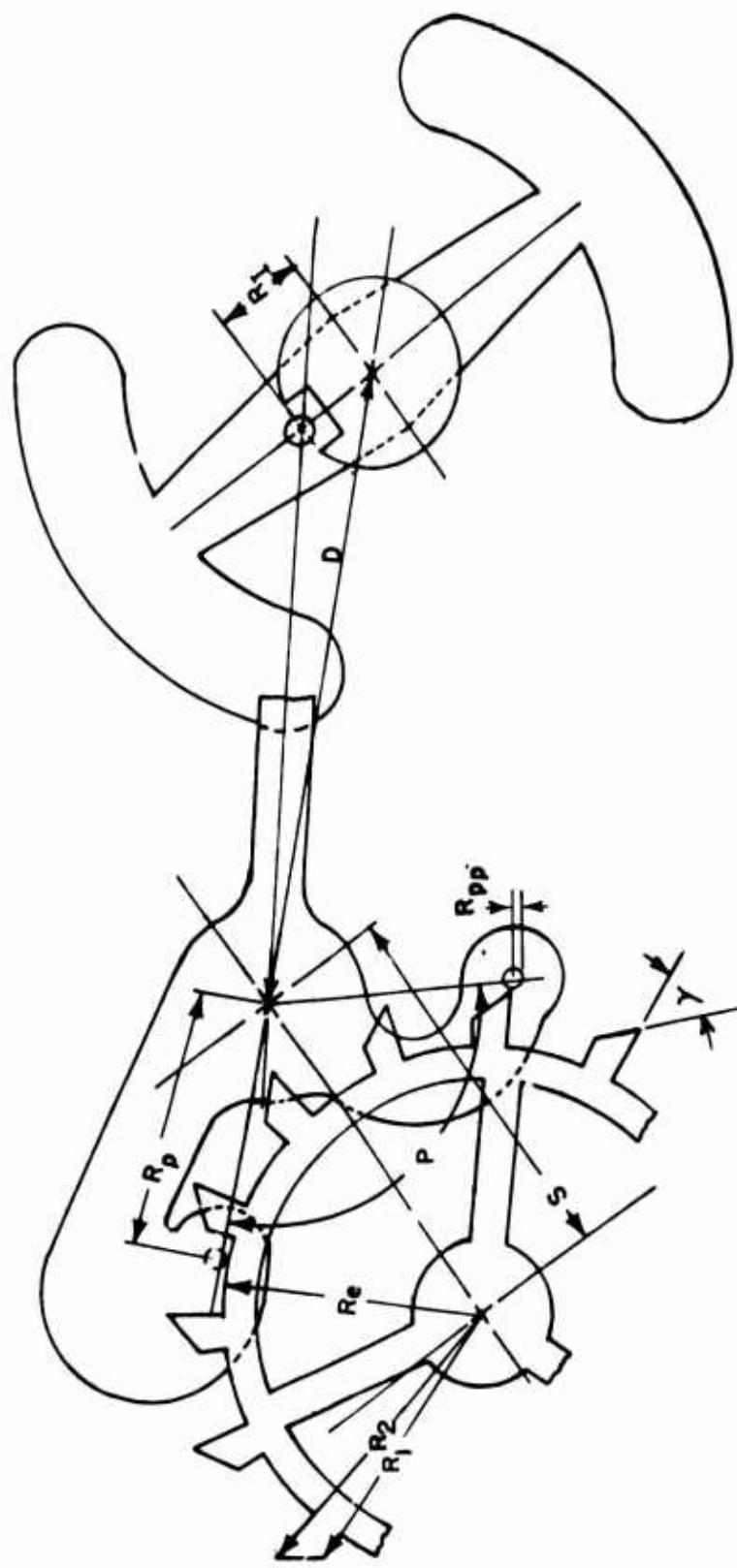


Figure 4. Escapement geometry.

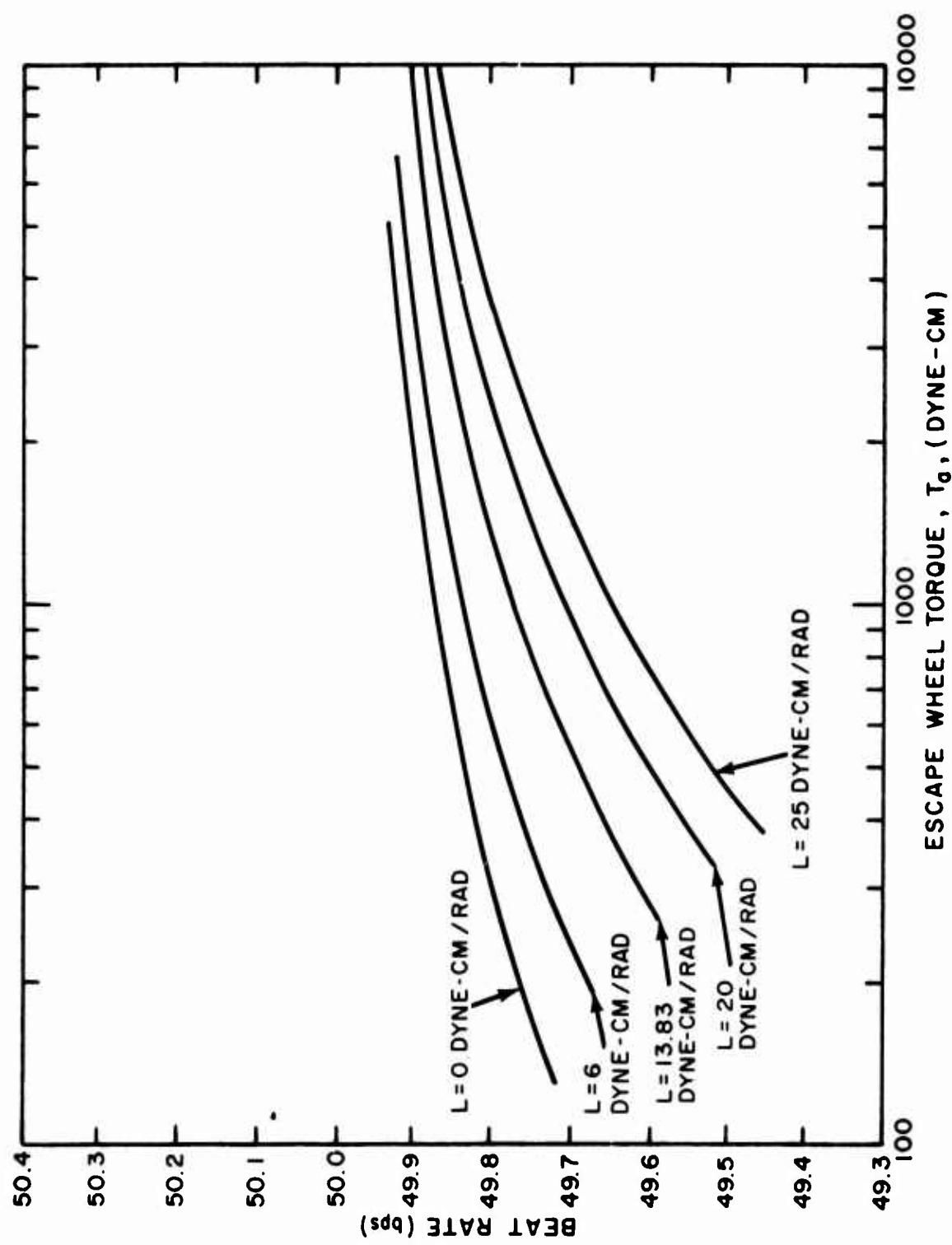


Figure 5. Theoretical beat rate curve for T5E1 escapement.

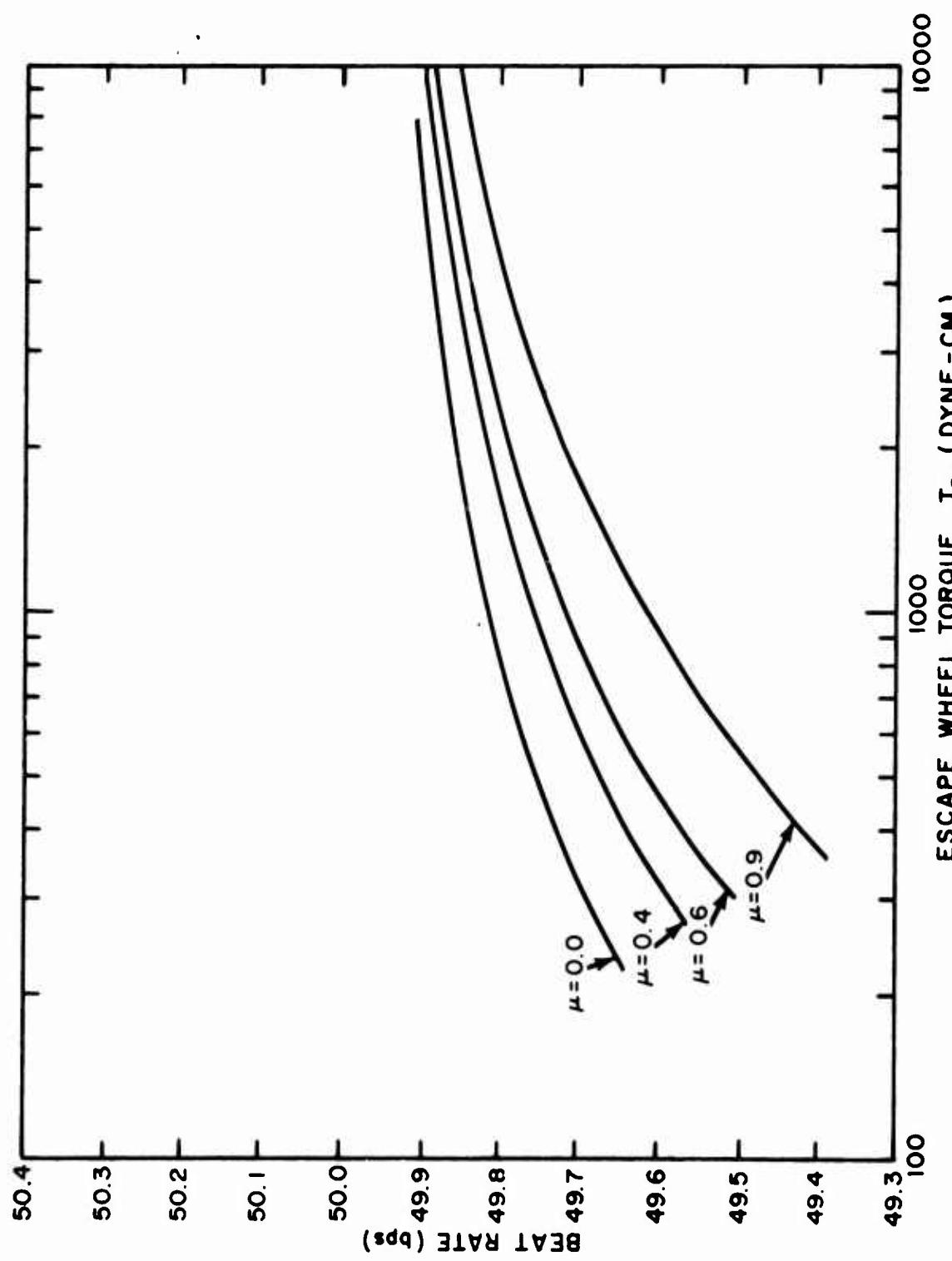


Figure 6. Theoretical beat rate curve for T5EI escapement.

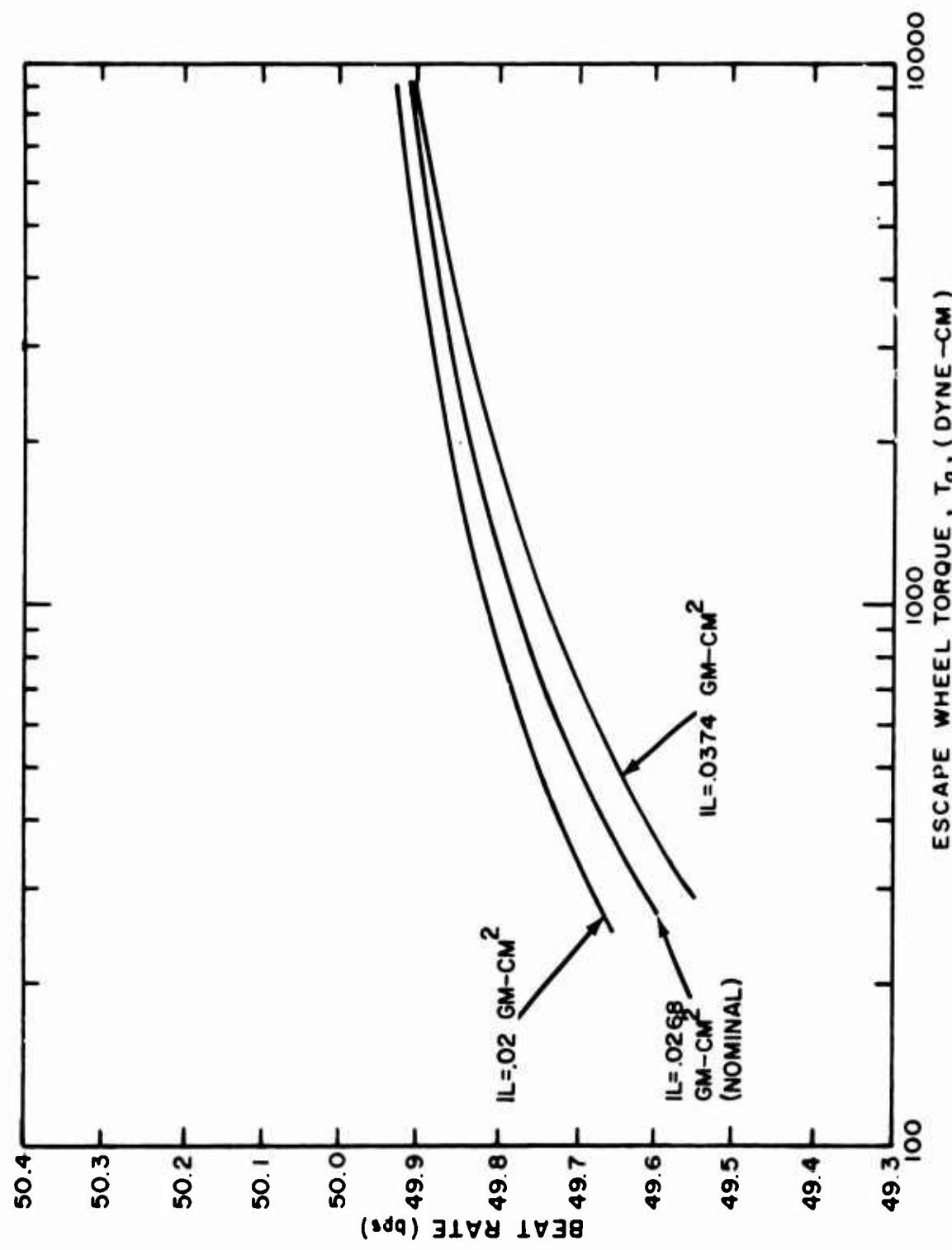


Figure 7. Theoretical beat rate curve for T5E1 escapement.

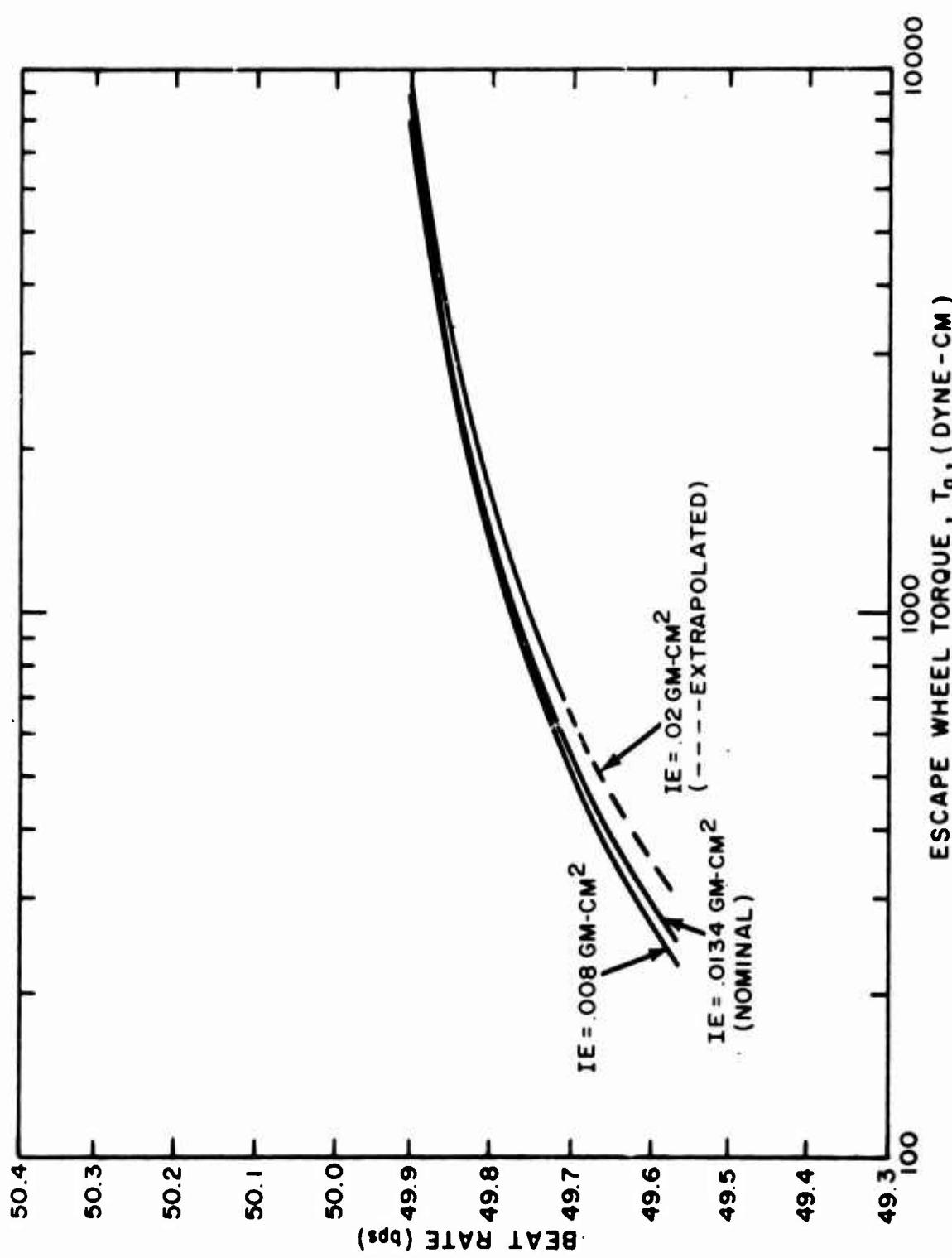


Figure 8. Theoretical beat rate curve for T5E1 escapement.

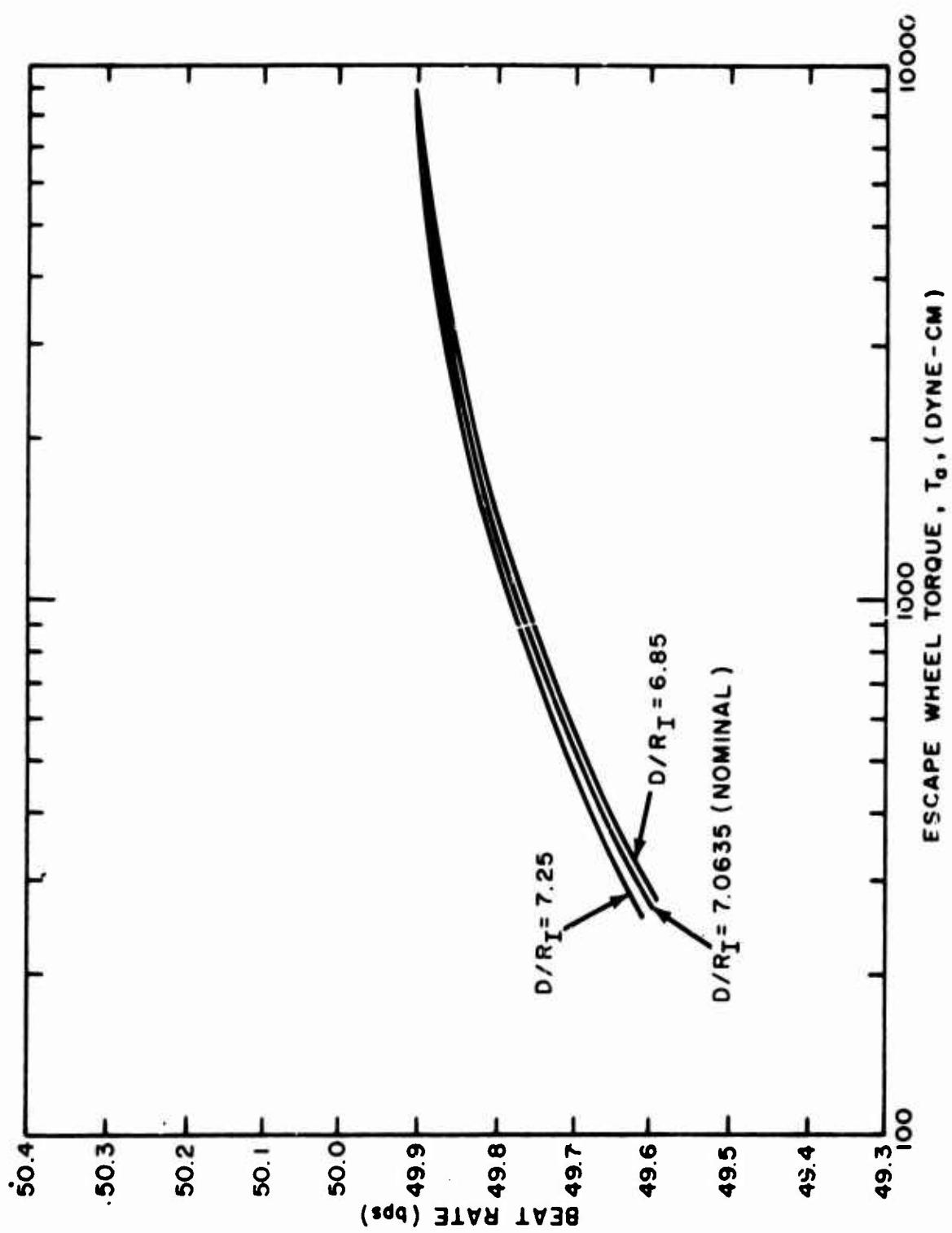


Figure 9. Theoretical beat rate curve for T5E1 escapement.

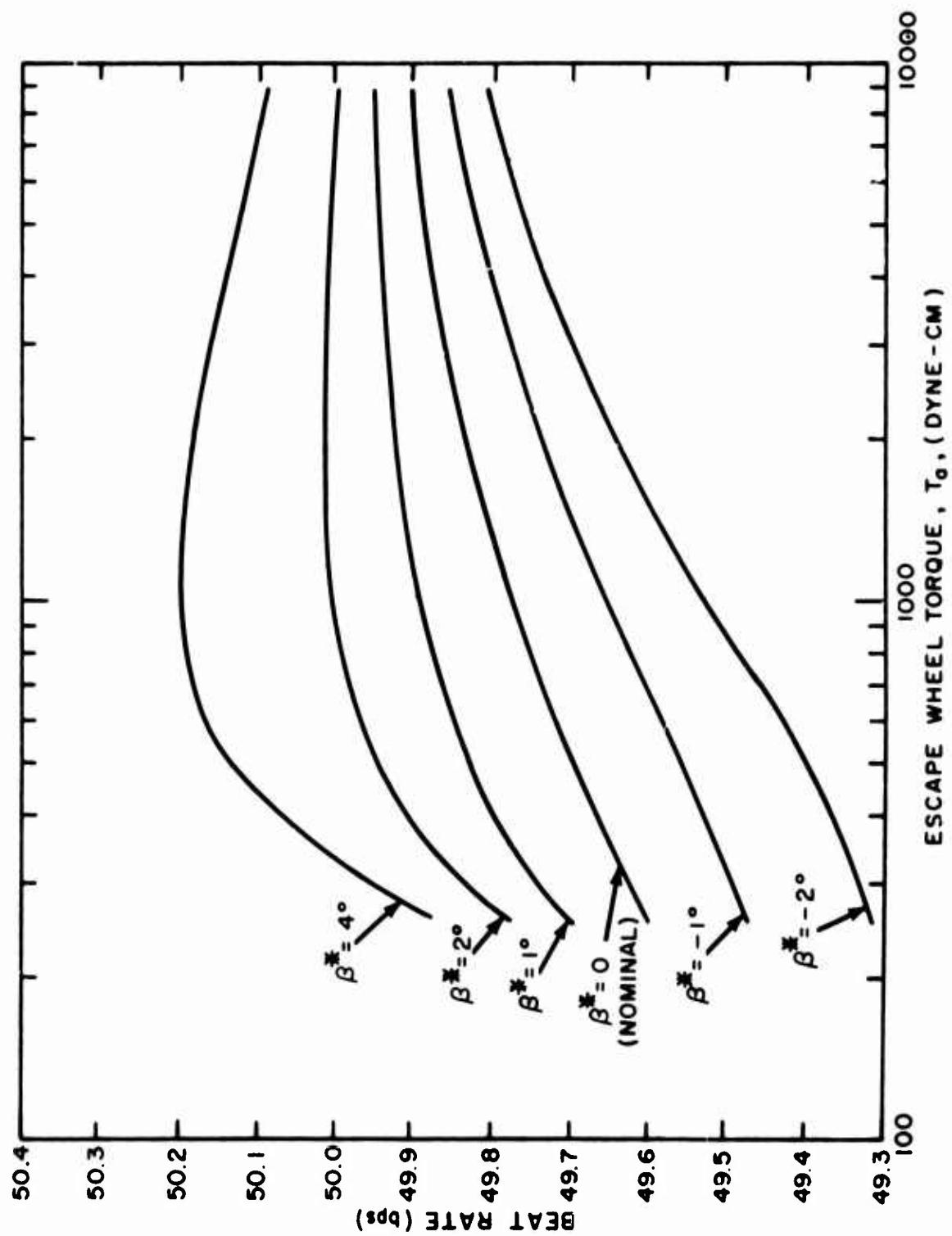


Figure 10. Theoretical beat rate curve for T5EI escapement.

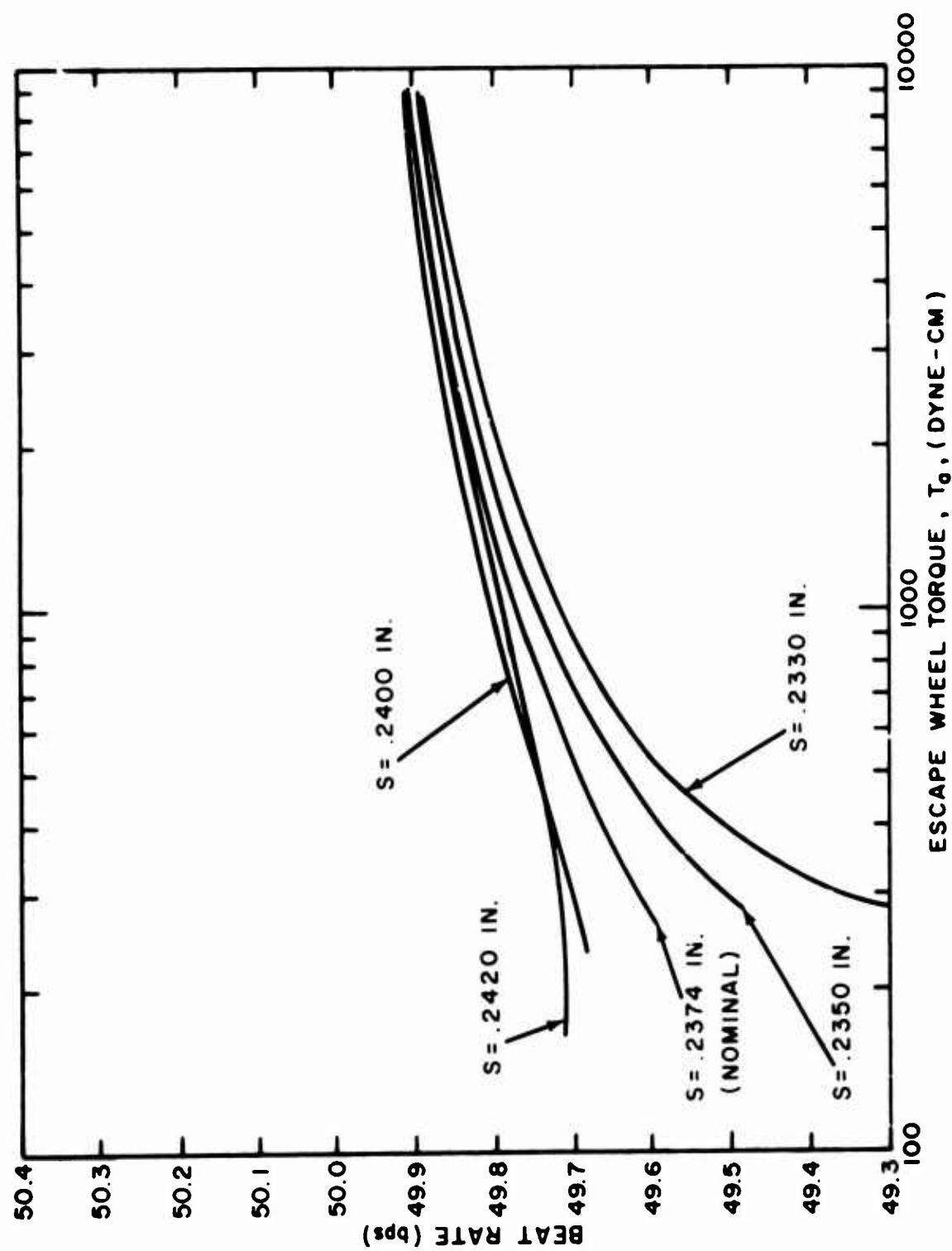


Figure 11. Theoretical beat rate curve for T5E1 escapement.

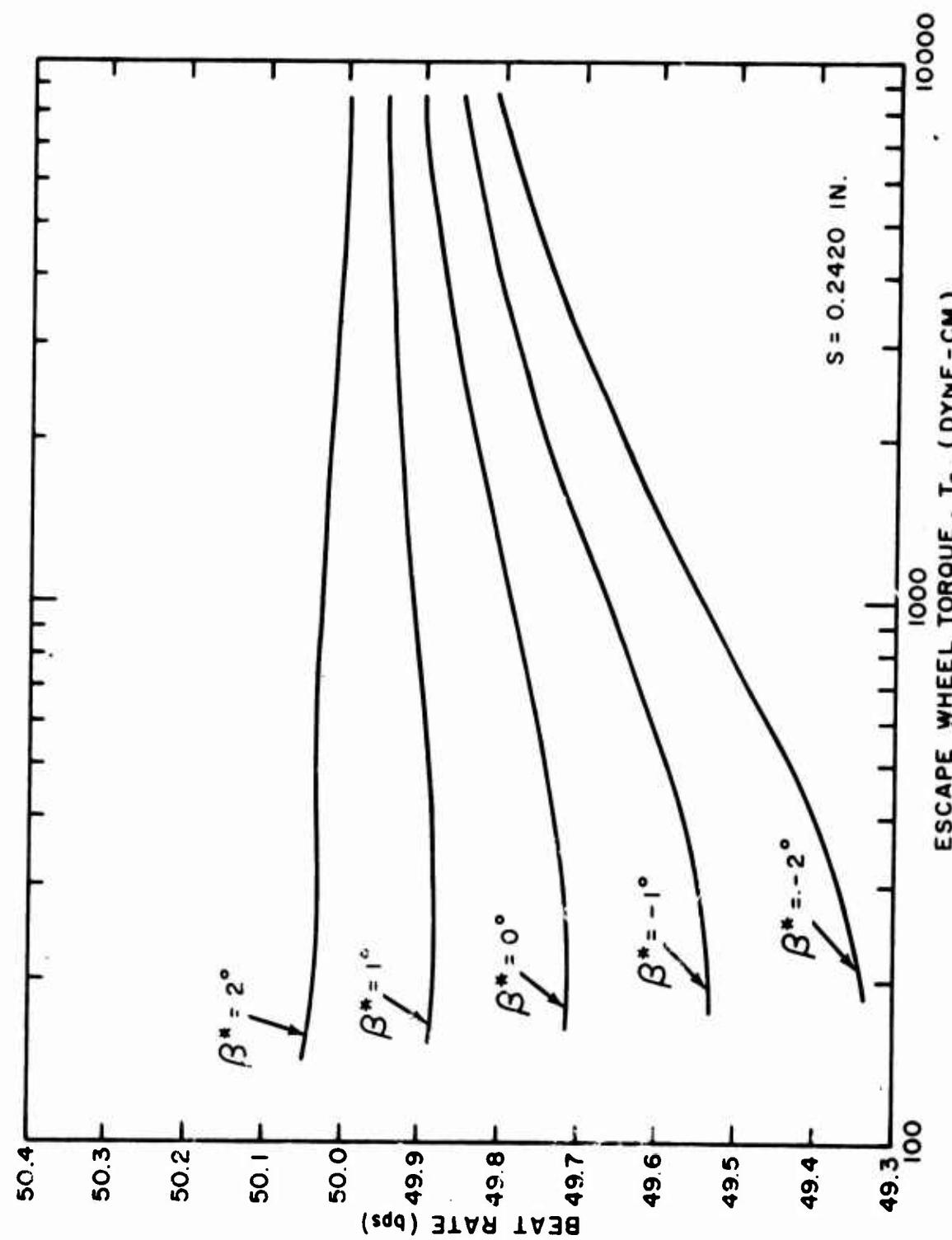


Figure 12. Theoretical beat rate curve for T5E1 escapement.

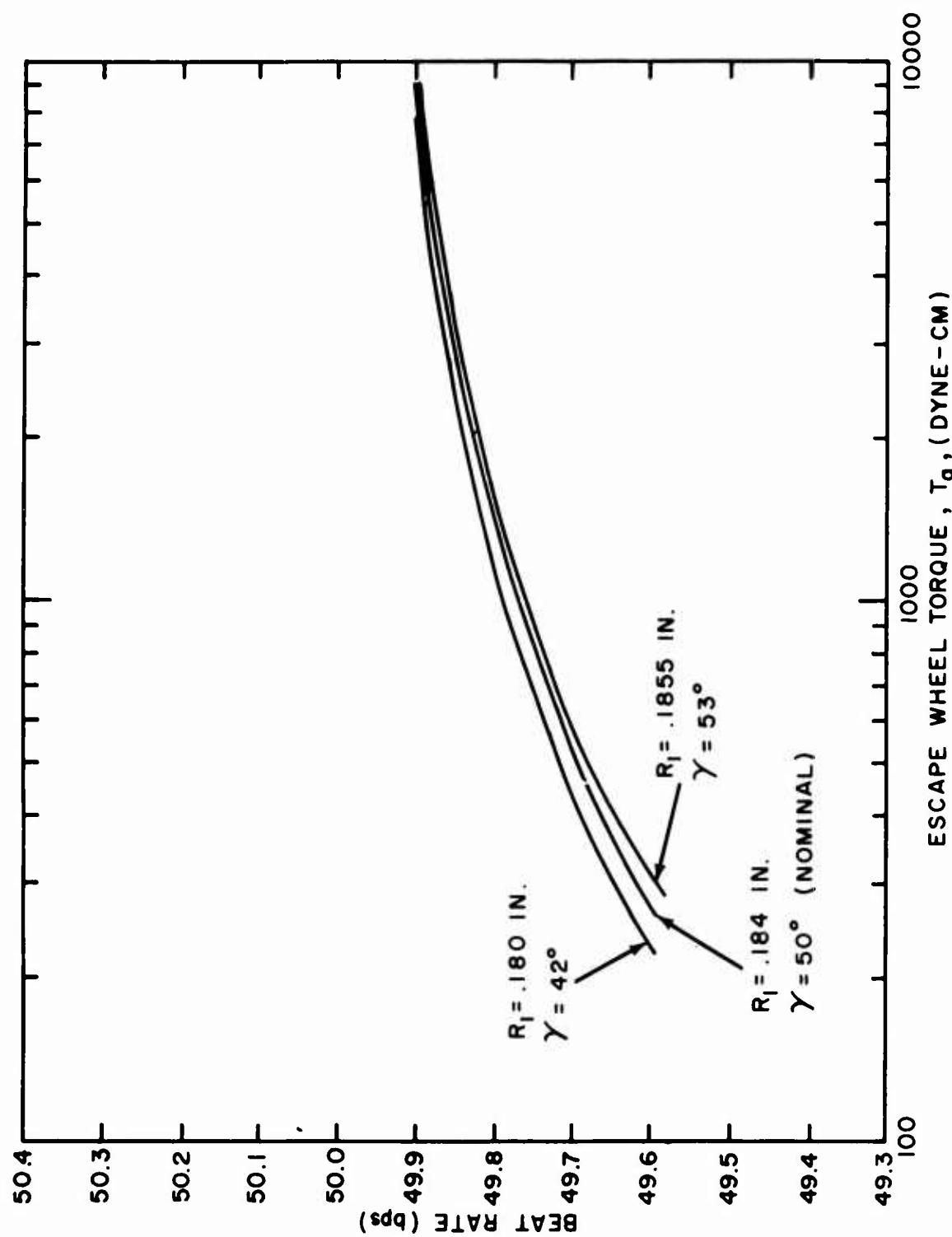


Figure 13. Theoretical beat rate curve for T5E1 escapement.

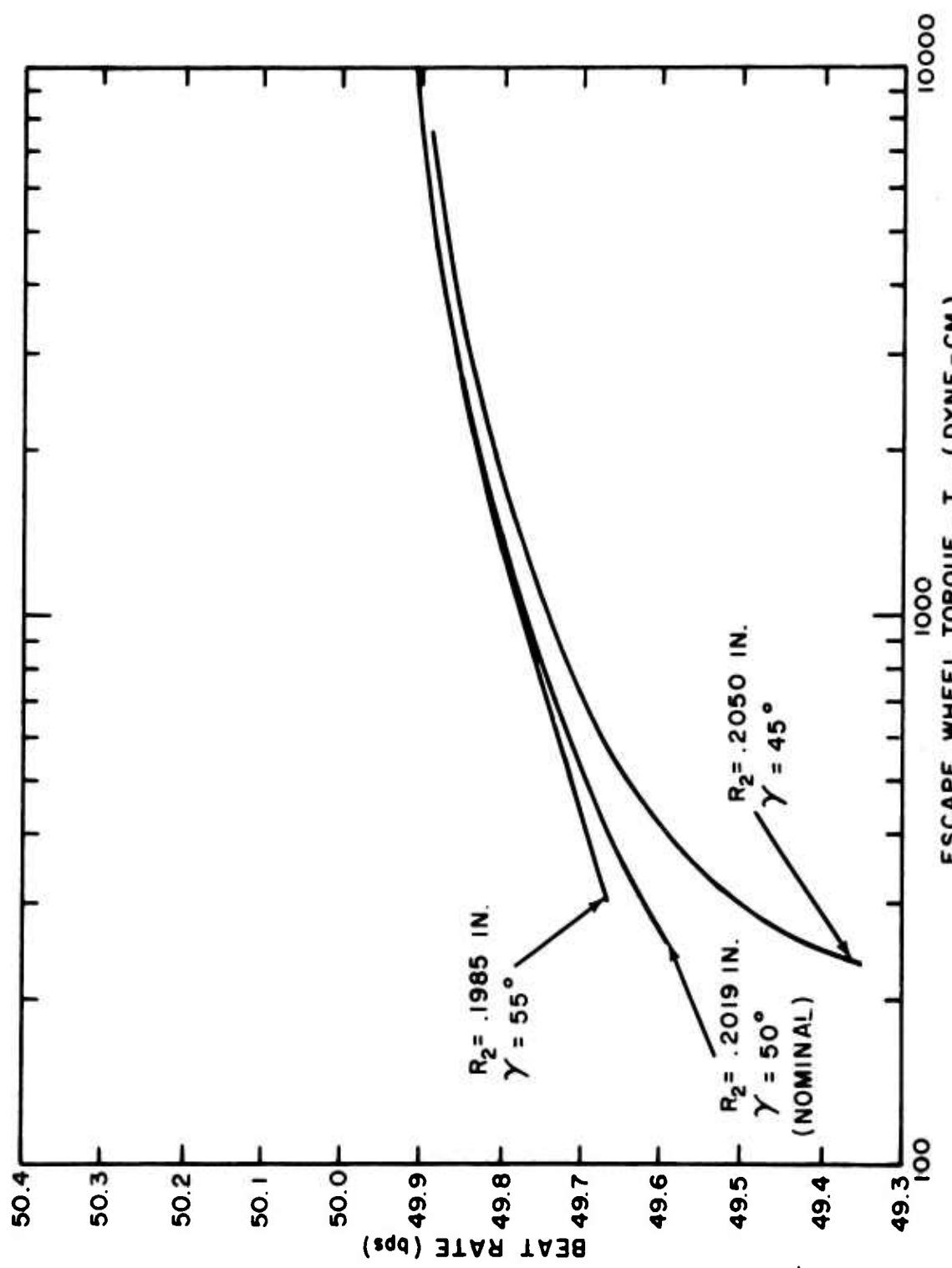


Figure 14. Theoretical beat rate curve for T5E1 escapement.

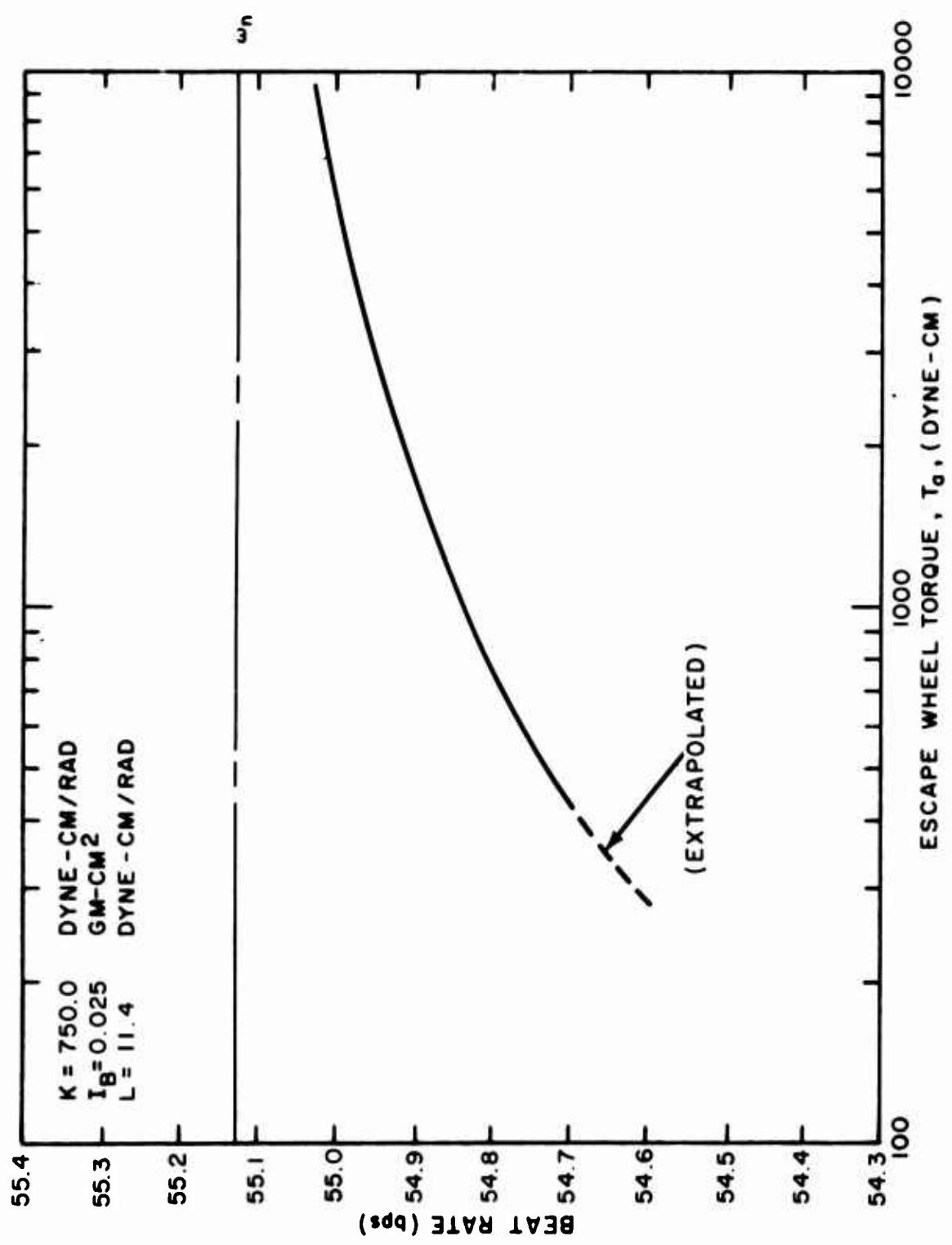


Figure 15. Theoretical beat rate curve for T5E1 escapement.

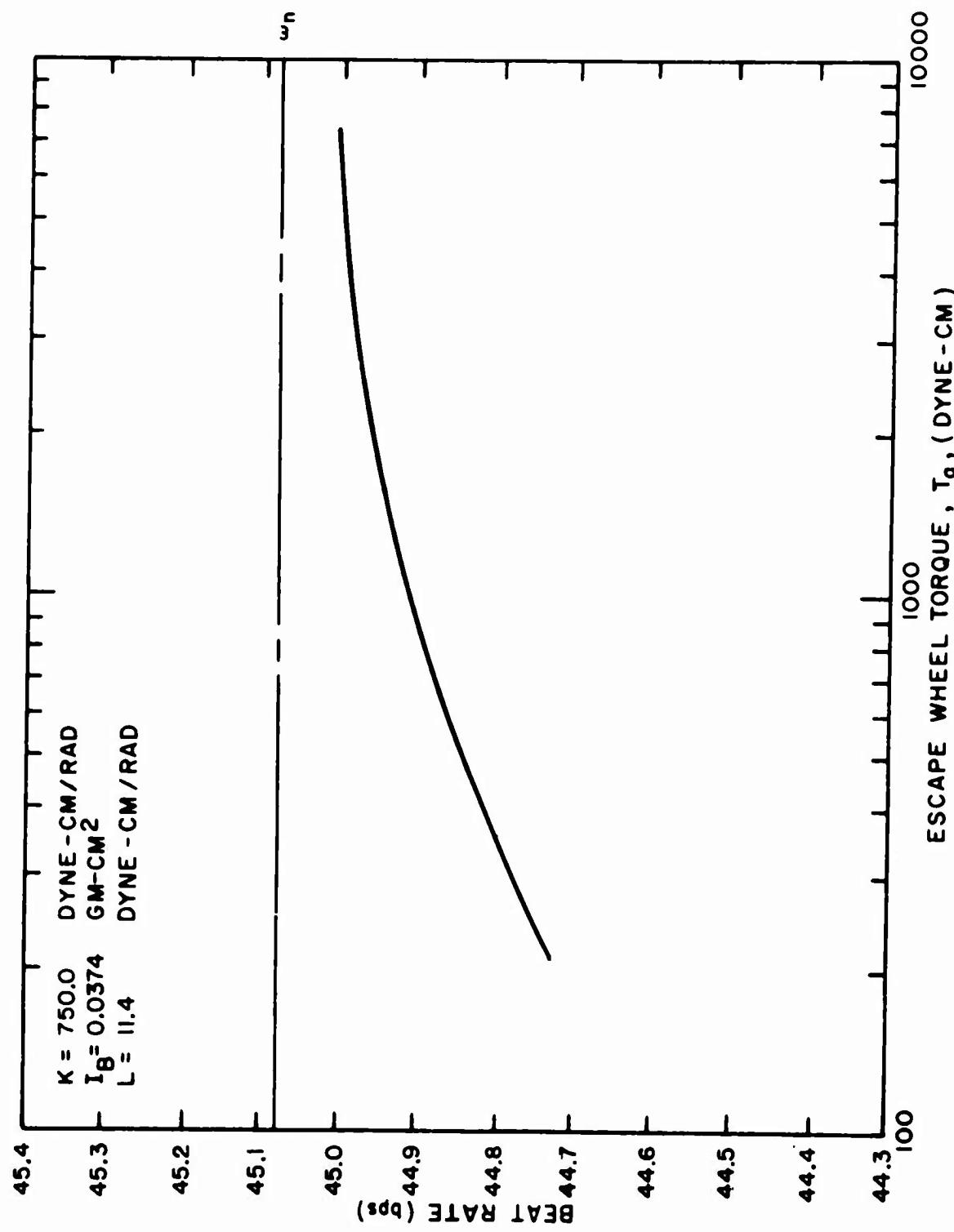


Figure 16. Theoretical beat rate curve for T5E1 escapement.

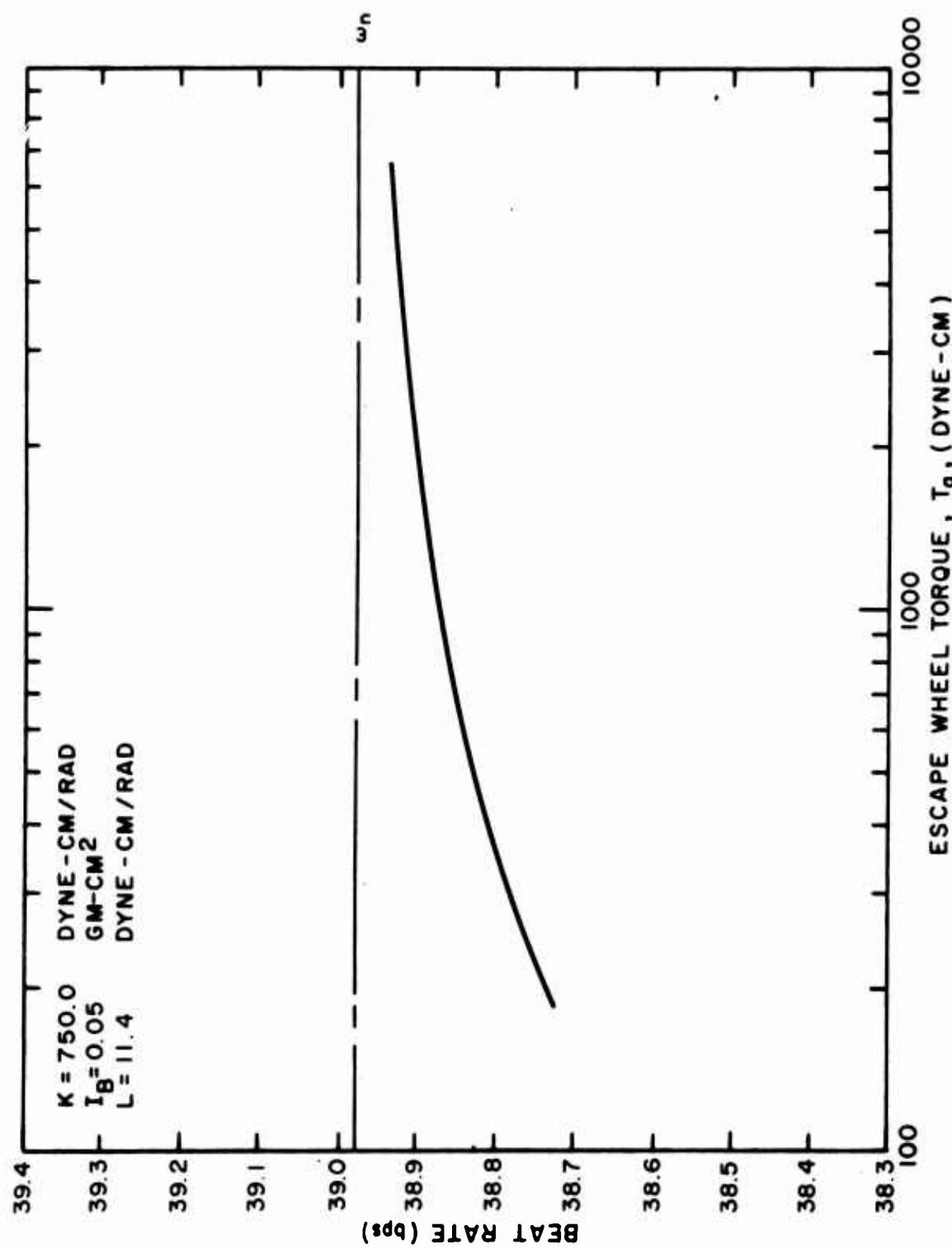


Figure 17. Theoretical beat rate curve for T5B1 escapement.

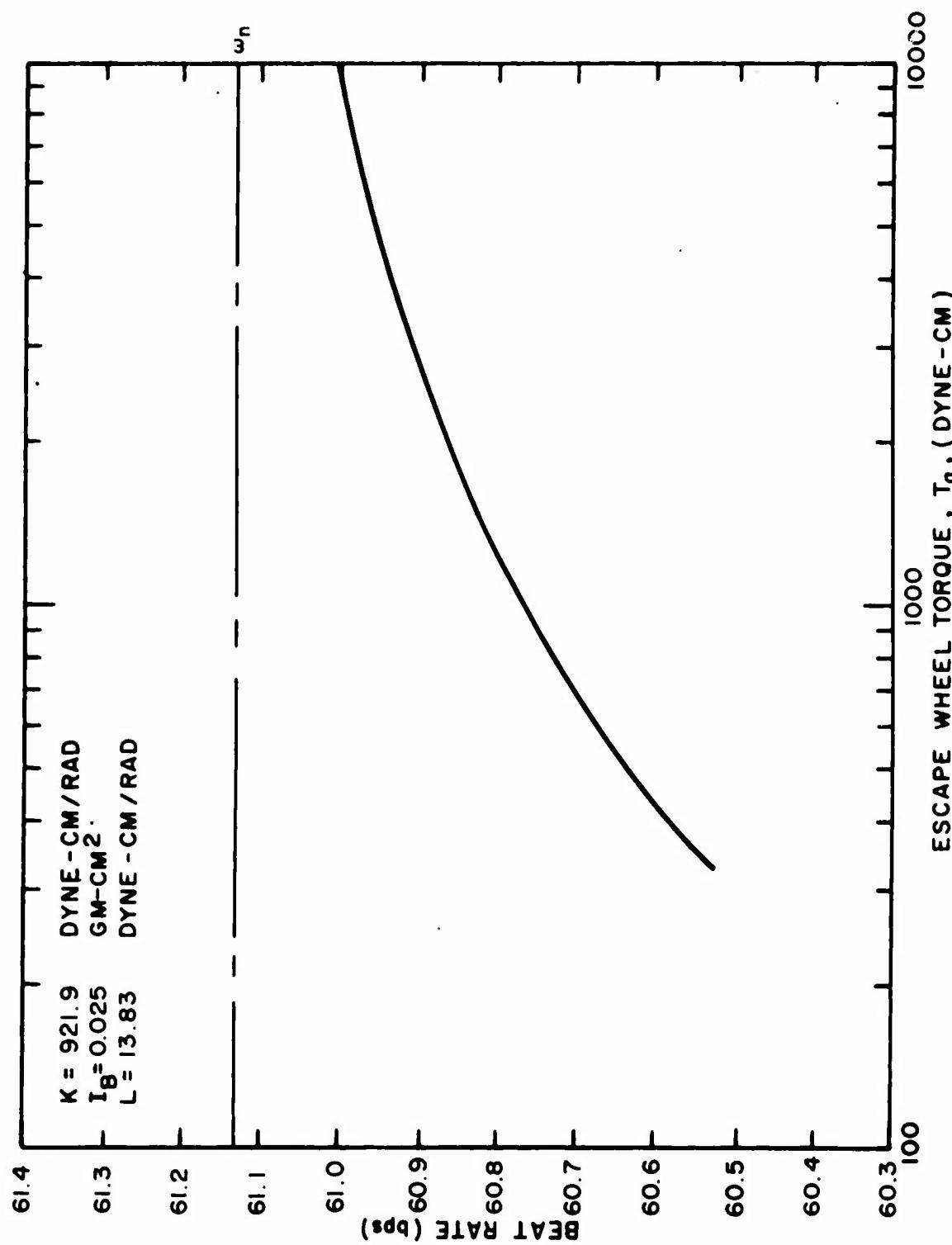


Figure 18. Theoretical beat rate curve for T5E1 escapement.

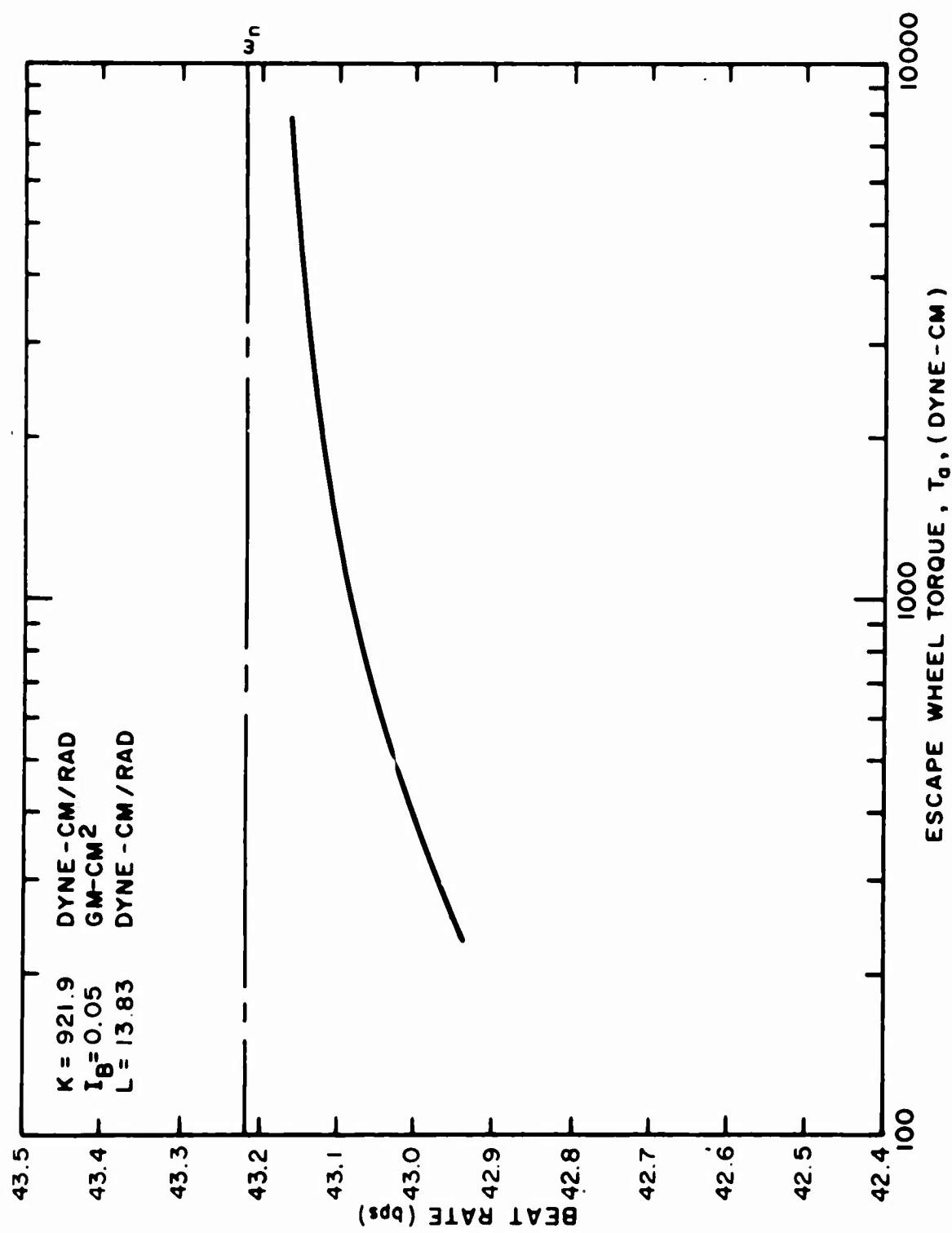


Figure 19. Theoretical beat rate curve for T5E1 escapement.

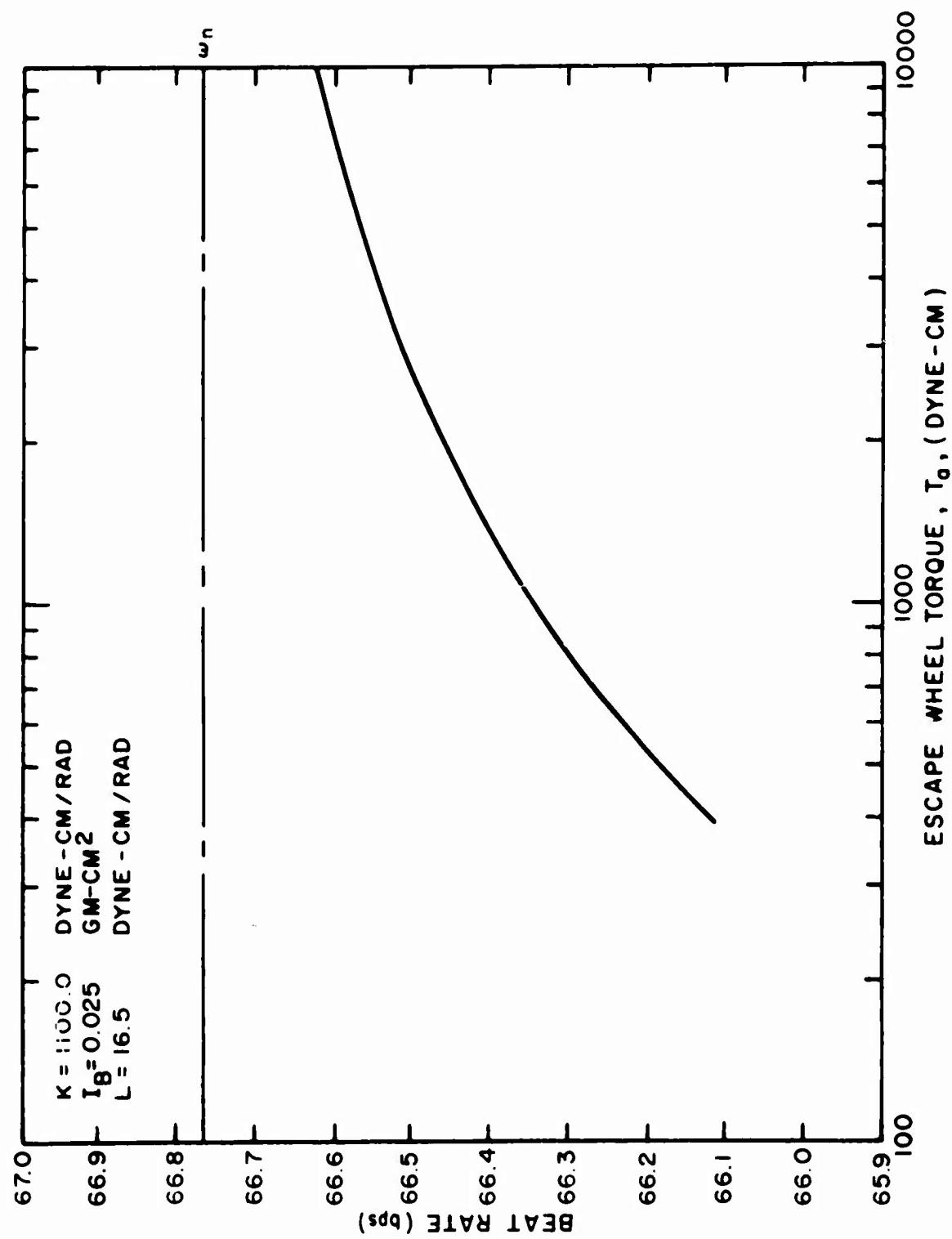


Figure 20. Theoretical beat rate curve for T5E1 escapement.

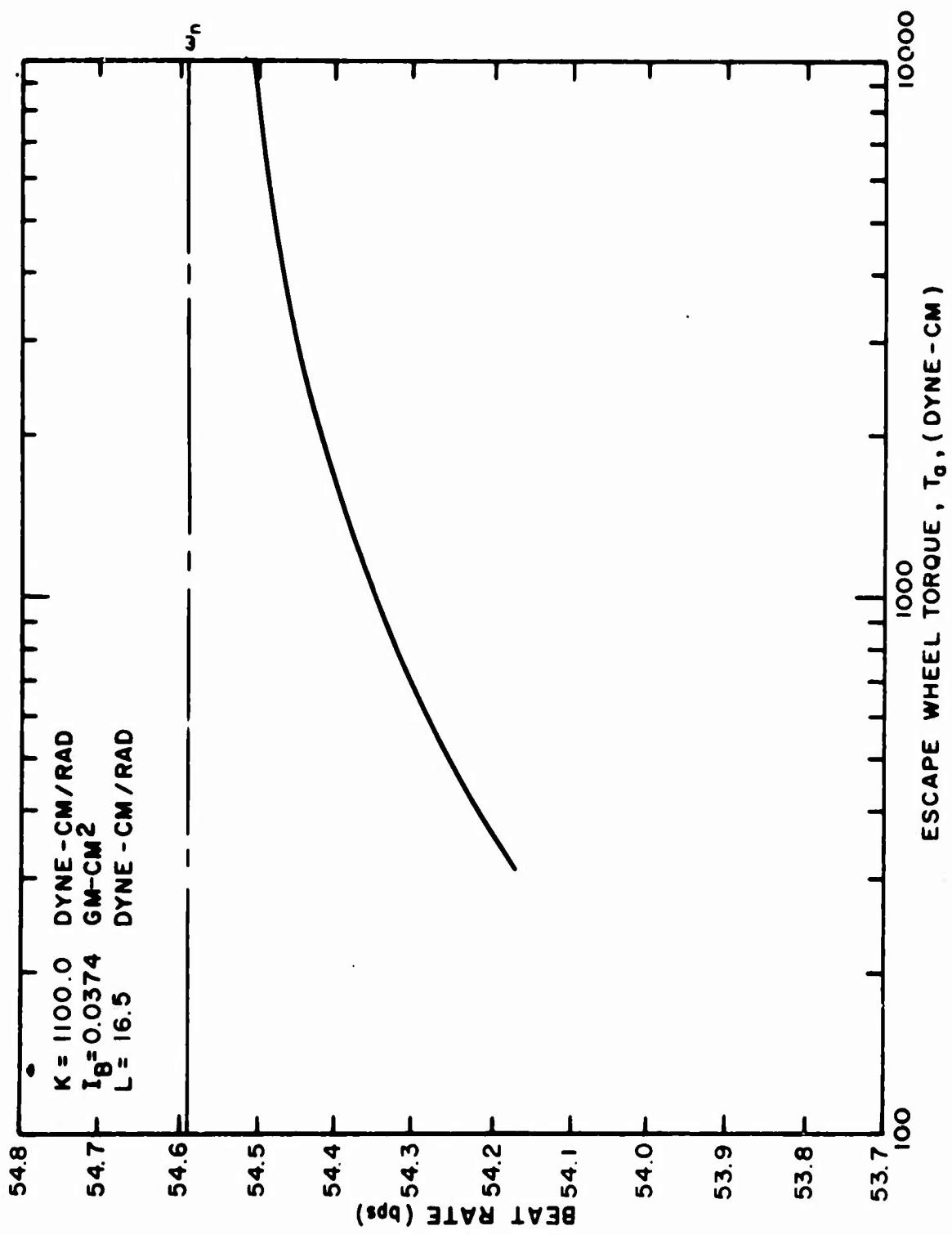


Figure 21. Theoretical beat rate curve for T5E1 escapement.

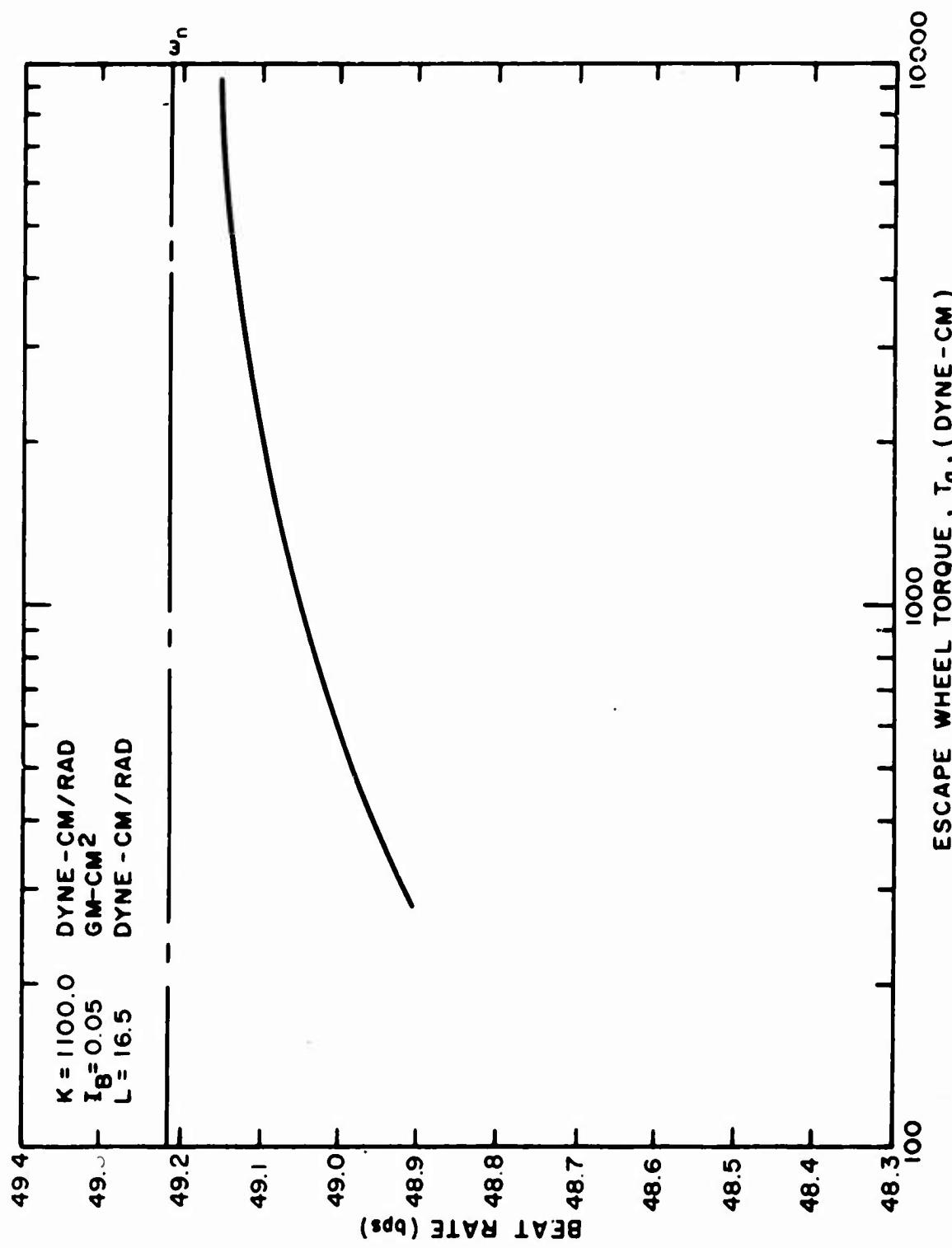


Figure 22. Theoretical beat rate curve for T5E1 escapement.

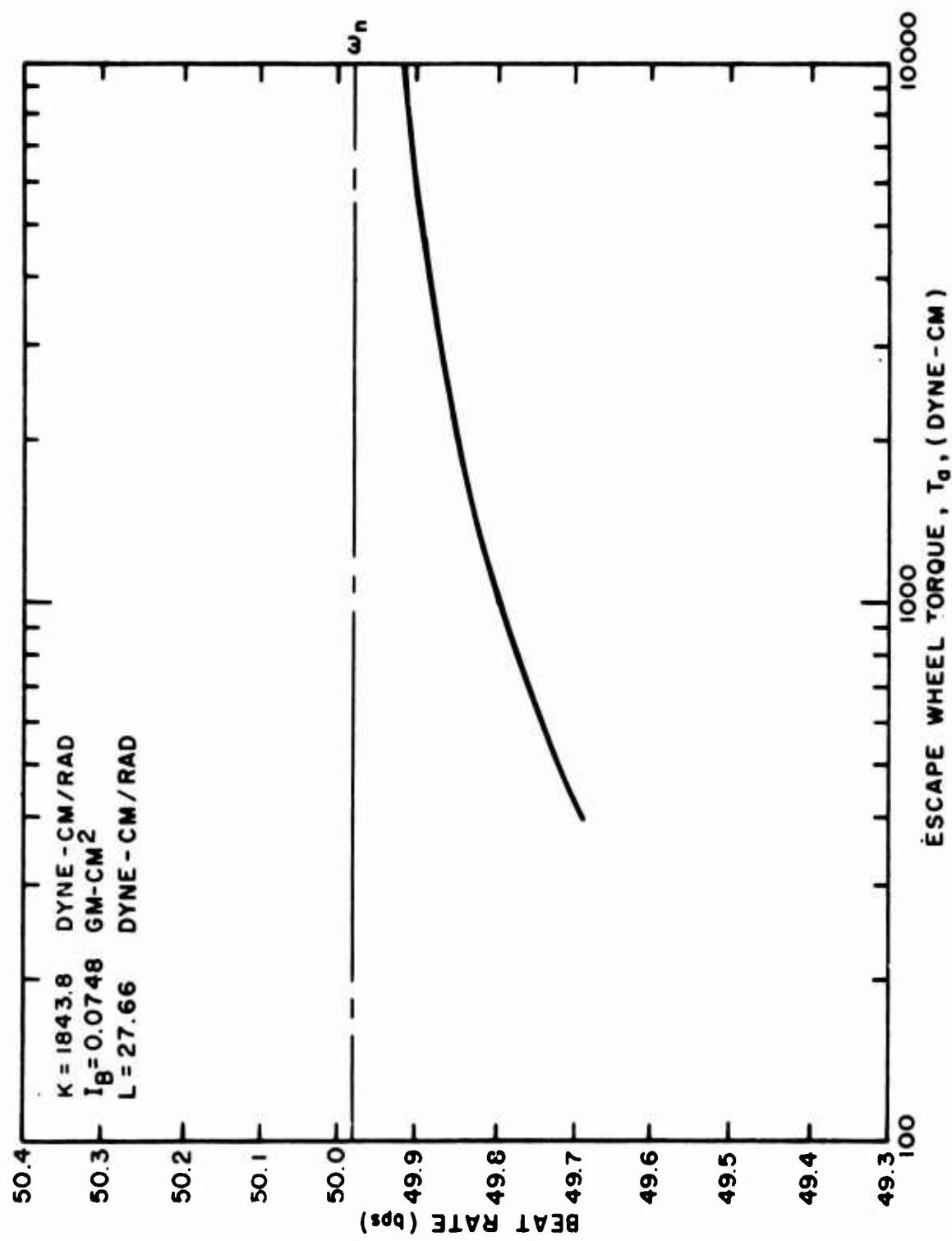


Figure 23. Theoretical beat rate curve for T5E1 escapement.

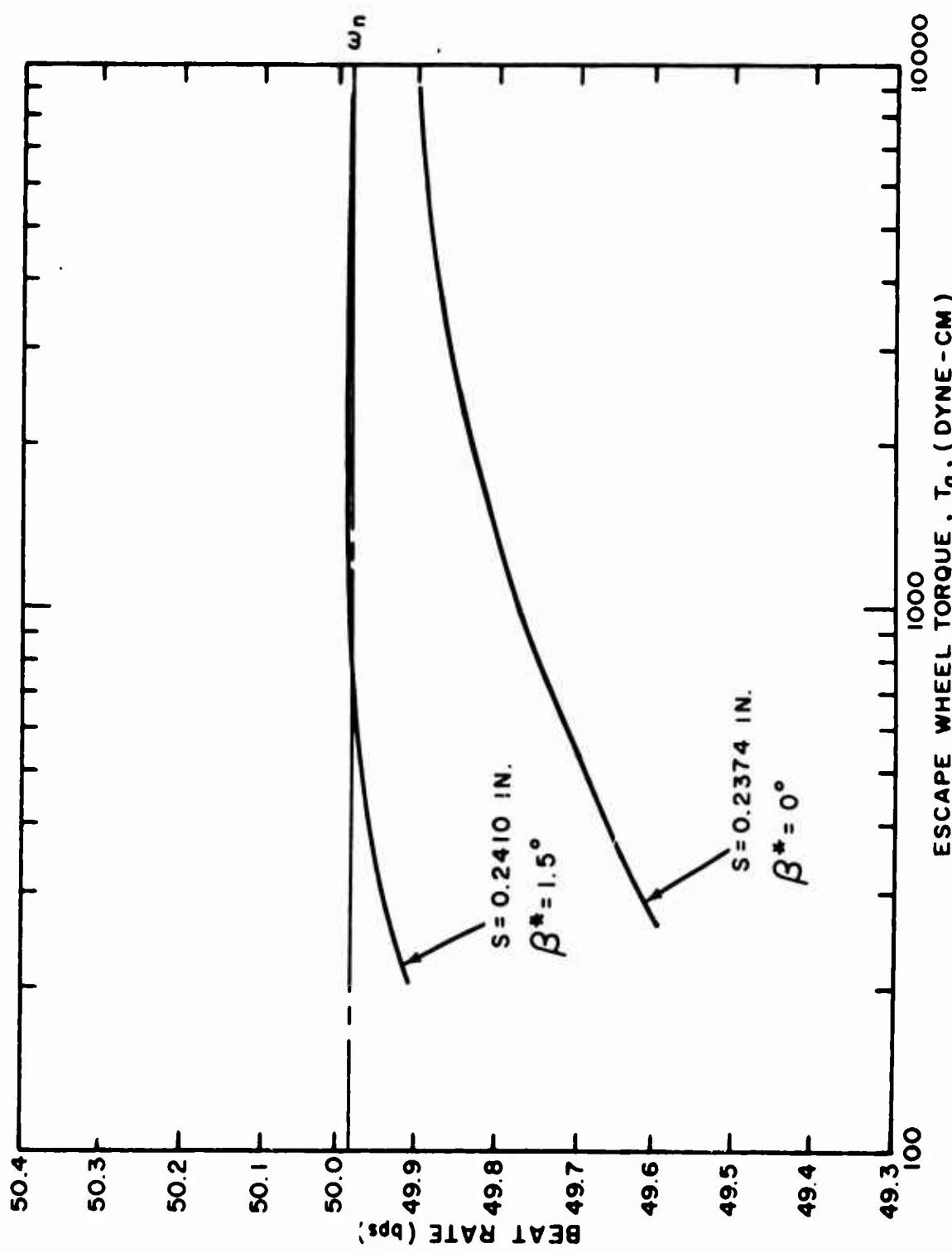


Figure 24. Theoretical beat rate curve for T5E1 escapement.

APPENDIX A

OPERATING INSTRUCTIONS FOR THE DIGITAL

COMPUTER PROGRAM BALCYC

ETC. (note neck)

Date: 1/15/95, Page 33.

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A-1 Sample BALCYC deck format:

1. Deck Setup

The deck is set up in the standard IBSYS format as illustrated in figure A-1.

2. Data Deck

Data are input via the NAME LIST facility of the IBSYS monitor. As usual, the first card of the data deck is a \$ DATA control card, \$ in column 1, DATA in columns 2-5. This is followed immediately by one or more case decks.

A case deck begins with a card with \$ DAT preceded and followed by one blank space. Data may begin on this same card, and each input item is referenced by a field of the form.

XXX = 527.903,

for instance, where XXX is an input variable name and 527.903 is the input value for XXX. The comma immediately following is mandatory. Blanks are not permitted within the field, but may be used at will between fields. See sample input deck.

Column 1 is ignored in all cards. Columns 2-80 are scanned for data.

Following are the inputs for the program:

ICND	= 0	, program sets nominal convergence criteria;
	≠ 0	, user supplies the following six convergence criteria.
ERR		Relative error in Simpson's Rule calculations (nominally 1.0E-7).
REL		Relative error in iteration for $\beta_3 \beta_9$, (nominally 1.0E-7).
RELM		Relative error in calculation of T_a (nominally 1.0E-7).
N		Initial number of points for Simpson's Rule (nominally 11).
NMAX2		Maximum number of points for Simpson's Rule (nominally 1000).
MMAX		Maximum number of iterations for finding T_a (nominally 20).

(If ICND = 0, these criteria need not be input.)

IGEM = 0 Recalculate geometry.

≠ 0 Same geometry as previous case.

(Should be set to zero for first case in every run.)

RE R_e , escape wheel root radius.

A,B Legs of triangle defining pallet geometry.

RPP, pallet pin radius.

BN Number of teeth on escape wheel.

SN Number of escape-wheel teeth spanned by pallets.

GAMMA γ , escape-wheel tooth face angle.

S, escape wheel-pallet center distance.

D/R_I, lever arm ratio.

UBI $I_U = \int_{\beta_2}^{\beta_1} U(\beta) d\beta$. If known input; otherwise set to zero. Must be changed in each case where geometry changes.

K, hairspring constant.

IB I_B , balance inertia.

IL I_L , lever inertia.

IE I_E , escape wheel inertia.

L, side thrust coefficient

MU, coefficient of friction during unlocking.

A₁, A₂, A₃ An initial estimate for T_a is taken from these parameters,

$$T_a = A_1(A_2+L)\beta_m^2 + A_3.$$

It has been found that, for the T5E1 mechanism, $A_1 = 12$, $A_2 = 16$, $A_3 = 40$ are suitable values. (c.g.s. units).

JA number of values of β_m for this configuration (case).

AMPL values of β_m for this case, JA in all.

R1 R_1 , escape tooth unlock radius.
R2 R_2 , escape wheel enter radius.
BSTAR β^* , out of beat angle.
IWRITE = 0, no intermediate output;
 $\neq 0$, intermediate output printed, usually of no
 value.

The symbol \$ must terminate each case. It may not be in column 1 of any card.

As many cases as desired may be run at one time. If certain parameters remain unchanged from case to case, they need not be re-input.

All error messages are deemed self-explanatory.

Any system of units is acceptable, as long as lengths are consistent within themselves and inertias follow the same units. For example, in the sample inputs, all lengths are in inches and all inertias in c.g.s. units. This is possible since all lengths go out as ratios. (Note that T_a will come out in torque units consistent with the system used, but will always be labeled dyne-cm.) All angles are input in degrees.

Sample output is seen in appendix B, and is deemed self-explanatory.

APPENDIX B
SOURCE PROGRAM LISTING
SAMPLE INPUT
SAMPLE OUTPUT

36 9/08 EXECUTE 175404-D,010,005000,HALEY
S1B708 JBLADN 080900Z SEP 08
S1B708 MAP
S1B708 BALYC

```

DIMENSION AMPL(20),BETA(13),RHD(13),EPS(13),T(20),TAO(20),BDOT(13)
1,11(13)
REAL K,L,IB,IL,IE,MU,L0,LD
NAMELIST/DOT/ICOND,ICOMD,IGEDM,RE,A,B,RPP,BN,SN,GAMMA,S,DRI,USI,
1,ERR,REL,RL,M,NOMAX,NMAX2,NMAX,K,ISIL,IE,L,MU,A1,A2,JA,AMPL,
2,R1,R2,IWRITE,BSTAR,A3
INTEGER ALARM
COMMON DR1,RPP,RS,AN,QE,KA,L1,IL,IE,MU,SN

C THIS PROGRAM IS DESIGNED TO CALCULATE THE PERIOD OF A DETACHED
C LEVER ESCAPEWHEEL SYSTEM FOR ONE CYCLE FOR A GIVEN INITIAL AMPLITUDE
C OF THE ANGULAR DISPLACEMENT OF THE BALANCE. ALSO INCLUDED IS THE
C CALCULATION OF THE APPLIED TORQUE AS A FUNCTION OF THE AMPLITUDE.

C INPUT
C RE,GAMMA, DEFINE GEOMETRY OF THE ESCAPE WHEEL AND TEETH
C A,B, DESCRIBE SIZE AND LOCATION OF THE PALLET PINS WITH
C RPP, PALLET PIN DIAMETER
C AN, NUMBER OF TEETH ON THE ESCAPE WHEEL
C S, NUMBER OF TEETH SPANNED BY THE PALLET PINS
C SN, SEPARATION BETWEEN THE LEVER STAFF AND THE ESCAPE WHEEL STAFF
C DRI, RATIO OF SEPARATION BETWEEN THE LEVER STAFF AND
C BALANCE STAFF TO RL (RADIUS OF THE IMPULSE PIN FROM
C THE BALANCE AXIS)
C AMPL, VALUE OF INITIAL AMPLITUDE OF BETA (CAN HAVE JA CASES)
C K, SPRING CONSTANT
C IB, IL,IE, MOMENT OF INERTIA OF BALANCE,LEVER,AND ESCAPE WHEEL
C L, TORQUE CONSTANT (IFL,BETA)
C MU, FRICTION CONSTANT

C ERR, RELATIVE ERROR IN SIMPSON'S RULE CALCULATION
C RELN, RELATIVE ERROR IN CALCULATION OF BETA FOR PHASE3
C NO, INITIAL NUMBER OF POINTS FOR SIMPSON'S RULE
C NMAX2, MAXIMUM NUMBER OF POINTS FOR SIMPSON'S RULE
C NMAX, MAXIMUM NUMBER OF ITERATIONS FOR PHASE3
C NMAX, MAXIMUM NUMBER OF ITERATIONS FOR FINDING
C IGE,OM, SET EQUAL TO ZERO FOR NEW CASES WITHIN A RUN
C S,DRI,SN,AN,A,B,R,P,B, AND GAMMA HAVE NOT CHANGED
C ICOND, IF ICOND IS EQUAL TO ZERO THEN THE PROGRAM CHOOSES
C RELN=REL=1.E-7,NO=11,NMAX=NMAX2=20,NMAX2=1000
C NO=REL=REL=1.E-7,NO=11,NMAX=NMAX=20,NMAX2=1000
C UNI, VALUE OF THE INTEGRAL OF U(BETA). IF SET EQUAL TO
C ZERO, THE PROGRAM WILL CALCULATE IT.
C A1,A2,A3, PARAMETERS FOR CALCULATING THE INITIAL GUESS OF TA
C IWRITE, IF INTERESTED IN INTERMEDIATE PRINTOUT IN SUBROUTINES
C T0RQ AND PHASE3, SET TORQUE EQUAL TO NONZERO
C VALUE, OTHERWISE SET EQUAL TO ZERO
C BSTAR, VALUE OF EQUILIBRITION POSITION OF BETA,USUALLY ZERO

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C      BETA      ANGULAR DISPLACEMENT OF THE BALANCE
C      RHO      ANGULAR DISPLACEMENT OF THE LEVER
C      EPSILON   ANGULAR DISPLACEMENT OF THE ESCAPE WHEEL
C      TA       APPLIED TORQUE
C      T        PERIOD OF CYCLE
C
C      PI=3.1415927
C      P1A=182./PI
C
C      INPUT
C      X=X*GAMMA
C      Y=Y*STAR
C      GAMMA=J.
C      BSTAR=J.
C      READ(J,DATA)
C      I=PARAM=J
C      IF(GAMMA.EQ.0.)GOTO500
C      GAMMA=GAMMA*PIA
C      GOTO 501
C
C      500  GAMMA=XX
C
C      501  CONTINUE
C      IF(BSTAR.EQ.0.) GOTO503
C      BSTAR=BSTAR/PIA
C      GOTO502
C
C      502  CONTINUE
C      SET CONVERGENCE CRITERIA IF ICOND=0
C      IF(ICOND.NE.0) GO TO 40
C      ERR=1.E-7
C      REL=1.E-7
C      RELM=1.E-7
C      NO=11
C      NMAX=20
C      HMAX=22
C      NMAR2=1000
C
C      40 CONTINUE
C      CALCULATE GEOMETRY
C      IF(IGEM.EQ.0) GO TO 89
C      CALL GEOM(IRE,A,B,APP,GAMMA,R1,R2,REE,R1E,R2E,PHI,OMEGA,OMEGA,E,Q,
C      1  LO,LD,E,RP,APP,BETA,RHO,EPSS,EPSS0,RH00)
C      89 CONTINUE
C      CALCULATION OF 081
C      IF(IUBL.NE.0.) GO TO 70
C      B1=BETA(1)
C      B2=BETA(2)
C      CALL UBICATERR,NMAX2,IWARM,B1,B2,UB1)
C      IF(IWARM.NE.0) WRITE(6,220)
C      33
C      WRITE INPUT
C      70  OMEGOMEGA*PIA
C      PHI=PHI*PIA
C      SAA=GAMMA*PIA
C      BSTAR=BSTAR*PIA
C      WRITE(6,301) RPP,REE,R1,R2,LD,O,OMEG,REE,REE,REE,REE,REE,REE,REE,REE,LD,E,
C      1  Q,OMEG
C      P1A*PIA
C      WRITE(6,312) GAA ,SN,BN,SP,AT,B,DR1,PHIN
C      34
C      WRITE(6,313) GAA ,SN,BN,SP,AT,B,DR1,PHIN
C      35

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BALCYC - EFN SOURCE STATEMENT - IFN(S) - 07/30/68 PAGE 3

```

P=PIA
      WRITE(5,303) K,L,IB,I,J,E,MU,UB,I,A1,A2
      WRITE(6,304) ERR,REL,RELH,ND,NMAX,NMAX,IPARM,ICOND,IGEM,
      1 IWHITE,OSTX,A3
      DO J=1,J=JA
      BETN=AMPLIJ*PI/180.
      TAO(I,J)=A1*BETAM
      C CALCULATE APPLIED TORQUE
      C ALSO BET3,BETA9
      JA=TAUJJ
      CALL TORQ1(BETA,RHO,EPS,TA,BETA4,NMAX,REL,IWARN3,IWARN9,NMAX,RELH,
      1 IALARM,T3,T9,BDOT,R1,E1,R2,E2,ER1,NMAX2,UB1,IWRITE,BSTAR)
      TAO(J,JA)
      IF(IALARM.NE.0) WRITE(6,202)
      IF(IWARN3.NE.0) WRITE(6,203) IWARN3
      IF(IWARN9.NE.0) WRITE(6,225) IWARN9
      TT3)=12
      TT19=T9
      C CALCULATE PERIOD FOR PHASE1 TYPE
      C INCLUDES PHASES 1,5,6,7,11,12
      DO 15 JJ=1,6
      NP=11
      IF(NP.EQ.1) GO TO 5
      NP=NP+3
      IF(IJJ.GE.5) NP=NP+3
      BETAU=BETAINP-1)
      P=1-BDOT(NP-1)
      EB=EPS(NP-1)
      EA=EPS(NP)
      GO TO 5
      5 BETAO=BETAM
      ADD00J.
      6 BETAF=BETAINP)
      BDOTF=BDOTINP)
      CALL PHASE1(BETA0,BDOT0,ED,EA,BETAF,TA,TP,BDOTF,NP,BSTAR)
      P=BETAINP)-BETAF
      BDOTF=BDOTINP)
      15 TTNP=TP
      C CALCULATE PERIOD FOR PHASE2 TYPE
      C INCLUDES PHASES 2,4,6,10
      DO 30 JJ=2,10,2
      IF(NP.EQ.6) GO TO 30
      BETAO=BETAINP-1)
      BETAF=BETAINP)
      BDOTF=BDOTINP)
      BDOT0=BDOTINP-1)
      CALL PHASE2(BETA0,BETAF,BDOTF,ED,ERR,NMAX2,TA,TP,BDOTF,NP,BSTAR)
      TTNP=TP
      IFIALARM.EQ.0) GO TO 30
      WRITE(5,204) NP
      30 CONTINUE
      T1J=TT11
      26 DO 26 M=2,12
      26 T(IJ)TJ+TTM)
      C WRITE OUTPUT
  
```

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80010=2
8MAMPL(J)
R0-RHO0*PIA
E0-EP50*PIA
WRITE15,2011 8M,8D,8D,80010
DO 8 M=1,12
 8V-BETA(M,PIA
  R-RHO(M)*PIA
  E=PS(M)*PIA
  8D-BDOT(M,PIA
  8 WRITE15,208) M,BV,R,E,TT(M),8D
10 CONTINUE
  WRITE15,209)
  AVE=0.
DO 25 J=1,JA
  25 AVE=2./T(J)*AVE
  AJ=JA
  BEAVE=AVE/AJ
DO 20 J=1,JA
  BEA=2./T(J)
  BRE=BEAT-BEAVE*100./BEAVE
  20 WRITE15,210) AMPL(J),TAQ(J),T(J),BEAT,BRE
  20 TO 1
301 FORMAT(1H,155X14ACLOCK GEOMETRY//16X3MRRP,9X2MRE,10X2MRRP,10X2MRRP,
  1 10X2MRE,10XIM,11XIMQ,11X5MNEGA/7M ACTUALS8(1X,F11.7),
  2/12H EFFECTIVE 8(1X,F11.7)///)
302 FORMAT(12*5MGMMA,8X4MSPAN,8X5MTEETH,8XIMHS,11XIMP,10XIMHA,11XIMB,
  1 11X4MDR,8X3MPhi/9X9F12.8///)
303 FORMAT(56X10MPARAMETERS//16X1MK,11X1MK,11X2MK,11X2MK,11X2MK,11X
  1 2MK,10XHUB1,10XHAL1,10X2HAZ2,8X13,8X6F12,6X2F12,6X//)
304 FORMAT(56X10MCONDITIONS//3X3MHR,7X3MHR,8X4MREL,4X2MNO,17H NM
  1 NMMAX,4X6HPARAM,3X5MHICOND,3X5MHICOND,8H TWRITE,6X5MHSSTAR,15
  3X2A3/311P10.1) 315,16,48,1PE20.8,CPF14.6)
  202 FORMAT(1H,51H THE APPLIED TORQUE DID NOT REACH THE DESIRED VALUE)
  205 FORMAT(57H BETAG FOR PHASE9 DID NOT CONVERGE TO THE DESIRED VALUE
  1 13)
  203 FORMAT(57H BETAS FOR PHASE3 DID NOT CONVERGE TO THE DESIRED VALUE
  1 13)
  204 FORMAT(1H,48H THE PERIOD HAS NOT CONVERGED PROPERLY FOR PHASE,14)
  207 FORMAT(//,7X8HPOSITION,15X4HBE1A,16X3HHAO,17XHEPSILON,13X6HPERIO
  1D,13X6HDDOT//,10XH 0,8X12PE20.8),20X,1PE20.8)
  208 FORMAT(1H,8X13,8X512PE22.,8)
  209 FORMAT(1H,5X9MANPLITUDE,11X14HAPPLIED TORQUE,8X6HPERIOD,12X9HBEAT
  1 RATE,10X15HBEAT RATE ERROR/28X7H0NE-CH,15X3HSEC,13X9BEATS/SEC,1
  20X3HPERCENTREL,1//)
  210 FORMAT(51PE20.8)
  220 FORMAT(4IMTHE INTEGRAL OF U(BETA) DID NOT CONVERGE)
  END

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07/30/68

PAGE 7

50
SIGFTC PH3

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SUBROUTINE PHASE3(EPS0,BD000,MAX,REL,T,A,T,N,IMARN,DEPS,BETAF,RHO.
1  EPS,BETL,ERR,MAX2,BETAO,WRITE,BSTAR)
1  DIMENSION ET(120,21),FT(100,21),H(100,21),FEB(100,21),BD(100,21),B(21),
1  N(12),COL2,DB(12,8H100,21),
COMMON DRI,PPE,S,BN,QE,KL,IB,ILIE,MU,SN
REAL K,L,IB,IL,IE,MU,IL,IO
IMARN=0
1F1 WRITE(NE,0) WRITE(6,102)
102 SG=NP=4
NR=2
1F1 NP=EQ.91 GO TO 6
C5=T/(12.*1E)
NR=1
1F1L EQ.2) GO TO 6
C  CALCULATE CONSTANTS
C2=K-L
C1=KL
P12=6.2831854
R1D=1./DRI
DDR=R1D*DRI
RPE=Q*PPE*RPE
SSQ=SS
RPE=KPE*S
TRPE=2.*RPE
ANG=2.1415927*(1.5-2.*SN/BN)
RS=RPE*Q+SSQ
P2=P12
C8=COS(BETA0)
X0=(CB-RID)/(DDR-2.*C8)
I10=IB+IL*X0*XD
110=IB+IL*XD
C  COMPUTE INITIAL CONDITIONS
6  NZ(NR)=0
DH(NR)=SIGN(BETL-ABS(BETA0))/10.**SG
DELB=OH(NR)/1000.
IM=1
BO(1,NR)=BETAO
CO(NR)=110*BD000*2.*C2*BETAO*2.-C2*BSTAR*BETAO
C  COMPUTE INTEGRAL
27  ITR=1
N1=1
N2=3
60  DO 12 J=N1,N2,NI
6  G=J-1
BE=GOELTB+BO(IM,NR)
COSB=COS(BE)
SINH=SH(NBE)
X=(COSB-RID)/(DDR-2.*COSB)
11=IB*X*X*IL
CC2
1F1 BE=LT*BSTAR)C=CI
12  H(11)=SQR(ABS(11/(CO(NR))-C*BE*BE+2.*C*BE*BSTAR))
1F1 (N1,E.0.2) GO TO 13
CB=COSB
SB=SINB

```

DIMNLDE

13 CALL SIMPH,DELTB,N2,ERR,SUM,LPI

1F1P,NR1,01 GO TO 45

45 IF(I1K,EQ,0.1) GO TO 45

J1LABL,SUM1-SUM1A,G1,00,ERR=ABS(SUM1) GO TO 45

SUM=15.*SUM-SUM1/15.

GO TO 35

45 ITR=2

SUM1=SUM

1F1N2,L1,NMAX2) GO TO 30

B(NR1)=B01IM,NR1

1M=IM-1

IWM=3

GO TO 72

32 DO 23 J=1,N2

JJ=NY2-1+1

J2=2+JJ-1

23 H(JJ2)=H(JJJ1)

N12

NY2=2+NY2-1

DELTB=DELTB/2.

GO TO 50

C CALCULATE TIME AND EPSIT

15 IF(I1M,NE,0.1) GO TO 16

FT1IM,NR1)=SUMMFT1IM-1,NR1

50 TO 17

16 FT1IM,NR1)=SUM

17 ET1IM,NR1)=EPS0-C5*FT1IM,NR1)*FT1IM,NR1)

C CALCULATE EPS(BETA)

UI=SB/DR1-CB1

RH1IM,NR1)=P2-ATAN(U1)

1F1NP,0.9) GO TO 10

RF=SQR(RS-TAPES*COSIRH1IM,NR1))

R=RKF

U1=UE/RF

U2=(RFNF+SSQ-RPEQ)/12.*SQR)

FEB1IM,NR1)=ARSIN(U1)-ARSIN(U2)

GO TO 20

10 AR=SQR(RS-TAPES*COSIP-RH1IM,NR1))

R=RR

U4=QE/RR

U3=(IRR1R*SSQ-RPEQ)/12.*SQR)

FEB1IM,NR1)=ABS(ANG+ARCOS(U4-ARSIN(U3)))

20 1F1ABS(FEB1IM,NR1)-ET1IM,IR1LT,REL*BS1ET1IM,NR1)) GO TO 70

1F1ABS(DLTB1,LT,1,E-0,ABS1BNR1)) GO TO 70

1F1IWRITE,NE,0,WRITE16,1011,14,FT1IM,NR1),ET1IM,NR1,FEB1IM,N

1R1DELTB,NZ(NR1),IWM

1F1I4,LE,NMAX1) GO TO 72

IWM=N2

GO TO 70

72 1F1FEB1IM,NR1,GT,ET1IM,NR1) GO TO 75

1F1NZ(NR1),EO,2) GO TO 75

DELTB,DH(NR1)/2.

65 IM=IM+1

B01IM,NR1)=B1IM,NR1

66 1F1ABS1D01IM,NR1)*2.*DELTB1,GT,0,ET1) DELTB=SIGN(ET1-ABS1B01IM,NR1)

243 - EFN SOURCE STATEMENT - IFNIS -

07/30/68

PAGE 10

```
1. IJ/2,15C)
GO TO 27
75 JF(LIM,GT,JI) GO TO 80
1WARN=1
GO TO 70
80 NI(NR)I2
D1=FEB(LIM-1,MR)-FEL(LIM-1,MR)
D2=FEB(LIM,MR)-FEL(LIM,MR)
DELTB=-(GO(LIM,MR)-B(MR))D1/(12.*D1-02)
DELTB=SIGN(DELTB)SGI
JF(FEB(LIM,MR),G1,FEL(LIM,MR)) GO TO 86
GO TO 85
79 FANSI(FITIM,MR)
EPS=FEB(LIM,MR)
DEPS=FAST/IE
BETA=RN(MR)
AMORBI(LIM,MR)
101 FORMAT(15.5,1PE15.5),215
102 FORMAT(15H IM,5X1HT,145MH0(NR),10X2MHT,13X3MHT,10X5MDELTB,9X2HNZ
1,6M 1WARN)
RETURN;
END
```

07/30/68

PAGE 13

5.
SILENT TORQUE

```

SUBROUTINE TORQBETA,RHO,EPST,TA,BETAM,T9,B001,A1E,12E,ERR,NMAX,X2,UBL,IMRTE,BSTAR
1  AELM,ALARM,13,T9,B001,A1E,12E,ERR,NMAX,X2,UBL,IMRTE,BSTAR
DIMENSION BETAL13(13),RHO(13),EPST(13),T100,F100,BD01(13)
COMMON DR1,PAPERS,BN,QE,K,L,10,IL,IE,MU,SN
REAL L,K,10,IL,IE,MU,11,112,11,12,129,113,114,119,129,110,1210
1  1123,124,1811
B01-BSTAR
1 ALARM=2
LL=1
B01=ABS(BETA1(4))
1 COUNT=0
1010=1
FACT=3
J=1
C COMPUTE CONSTANTS
P12=3.2831854
B15=BETAL11*BETAL11
B1=BETAL11
CALL FUNCT(B1,1,111,12,X,Z,E,R)
B01A=118/111
SQR1=(K-1)*(18E-AM-857)*2-(B1-B57)*27/18
6001(1)=B01A
B2=BETAL2
B25=B2*2
CALL FUNCT(02,1,112,12,X,Z,E,R)
B4=BETAL4
E4=EPS14
CALL FUNCT(B4,2,114,12,X,Z,E,R2E)
B10=BETAL10
E10=EPS10
CALL FUNCT(B10,3,1110,1210,X,Z,E10,R2E)
ID1=18/111
AA=K*((12/0/18-B111)*L*(1210/18+B111)
AB=K*((1111-(124*(1210)/12)*(1811)-(1*(1811*(124*(1210)/(12*(1811)-2)))/
AC=K*((124/18-B111)*L*(124/18+B111)
AD=BETAL11*BETAL11*AB
AE=BETAM*BETAM*AA/2.
AF=AE+AD
T(1)=TA
1 ITERATE TO FIND TA
30 TA=T(1)
B025=((K-1)*(B1-B57)*2-(B2-B57)*2)  +  111*B01A*22-2.*B01A
1 *UBL1/112
B02=-SQR1(B025)
3001(2)=002
E2=EPS12
B2=BETAL2
CALL PHASE3(E2,BD2,NMAX,REL,TA,TP,3,IMRTE,B3,R3,E3,R,LL,BETL
1  ,ERR,NMAX,82,IMRTE,BSTAR)
T3=TP
RHO(3)=R3
EPS(3)=E3
BETA(3)=B3
CALL FUNCT(B3,2,113,123,X3,73,E,R)
B03B=(112*B025+*(1182-B57)*2-(B3-B57)*2-L*(182-B57)*2-
1 SIGN(1.*B3-B57)*(B3-B57)*2)/113

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INRQL - EFN SOURCE STATEMENT - JEN151 - 07/30/68 PAGE 15
 803B=-SQRT(803BS)
 803A=(113*803B+13*8023*IE*ED381)/123 23
 1.F(ABS(803A).LT.ABS(803B))803A=803B
 800T13=003A
 803S=1.1./J241.011(23*803A**2*K*[(83-BST)**2-184
 1.L*(184-BST)**2*SIGN(1.,83-BST)*(83-BST)**21*2*TA*(E3-E4)) -BST)**21-
 804=-SQRT(804S)
 800T14=804
 808TS=(8 4-BST)**218*804S/(K+L)
 86=8ST-SQRT(808TS) 26
 8E1A(6)=86
 8S=86*86
 87=8E1A(7)
 807BS=(K-L)*(186-BST)**2-(87-BST)**2/18 27
 807A=(187/111)*SQRT(807BS)
 800T17=807A
 88=8E1A(9)
 803S=(1.1./112)*(1K-L)*(187-BST)**2-(188-BST)**2-2.*MU*UB1*TA*111-
 1.807A**2 28
 8D8=SQRT(808S)
 800T18=808
 88=EPS18
 CALL PHASE3(808,808,NMAX,REL,TA,TP,9,INARN9,ED98,89,89,E9,R,LL,8ETL
 1.8RQ,NMAX2,88,1WRITE,8STAR)
 LL=2
 19*TP
 RHO(19)=R9
 BETA(19)=89
 EPS(19)=E9
 CALL FUNCT(89,3,119,129,X9,29,E9,R) 33
 803BS=(1./119)*(112*808S*(188-BST)**2-(189-BST)**2)
 1.-L*(188-BST)**2*SIGN(1.,89-BST) * (189-BST)**2) 34
 809B=SQRT(808S)
 8D9A=(119*HD98-99*29*1E*EU98)/129
 1.F(ABS(809A).LT.ABS(809B))809A=809B
 800T19=8D9A
 801JS=(1./1210)*K*(189-BST)**2-(810-BST)**21*129*8D9A**2
 1.-L*(810-BST)**2*SIGN(1.,89-BST)*(89-BST)**21*2.*TA*(E9-E10)) 35
 2.
 801JS=SQRT(801JS)
 800T111=8D10
 8-AF*BSSAC/2
 3CC=.5*(123*803A803A-113*803BS*129*8D9A-119*809BS)
 C=2.*MU*881
 1.F(1J)=15CC-B1/C
 1.F(1J)1WRITE,ME,01 WRITE(6,101) J,T(1J),F(1J),83,89
 C CHECK FOR CONVERGENCE
 1.F(1J),L1,0,1 GO TO 50
 1.COUNT=1
 1.F(1J),EQ,1,1 GO TO 70
 1.F(ABS(F(1J))-T(1J)).LE.REL=ABS(T(1J))) GO TO 80
 1.F(ABS(F(1J)-T(1J)).LE.REL=ABS(F(1J))) GO TO 80
 1.F(ABS(F(1J)-T(1J)).LE.REL=ABS(T(1J))) GO TO 80
 1.F(1J+1)=T(1J)-(F(1J)-T(1J))11*(T(1J)-T(1J-1))7 (F(1J)-T(1J)-T(1J-1))7
 1.F(1J,GE,8MAX) GO TO 90
 1.GOTU 75

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      50 IF(J,NE,1) GO TO 55
      IF(I1D1D,EQ,2) GO TO 58
      T=R(J)
      FR=F(J)
      TJJ=(1.-FACT)*TR
      1010=2
      IEXP=1
      GO TO 30
      58 IF(F(J),LE,FR) GO TO 59
      TNEW=(TR-T(J))*FR/(FR-F(J))*T(J)
      TR=T(J)
      FR=F(J)
      TJJ=TNEW
      GO TO 56
      59 IEXP=1
      IJJ=(1.-FACT)*IEXP
      GO TO 56
      56 ICOUNT=ICOUNT+1
      IF(ICOUNT.GT.10) GO TO 90
      GO TO 30
      55 TJJ=(T(J)+T(J-1))/2.
      GO TO 55
      70 T(J+1)=F(J)
      75 J=J+1
      IF(T(J).LT.0.) T(J)=T(J-1)/2.
      GO TO 32
      90 IALAKM=1
      80 TA=T(J)
      C COMPUTES ENERGIES
      TE=5.*BETAM*BETAM
      C EQUIVALENT ESCAPEMENT ENERGY BALANCE
      C ENERGY GAINS
      FCCC=5.*(123*BD3A*BD3A-113*BD3BS)
      FCI=TA*(EPS13-EPS14)
      AGCC=5.*(129*HD9*BD9A-119*BD9BS)
      RCI=TA*(EPS19)-EPS10)
      C TOTAL ENERGY GAIN
      TG=FGCC+FG1+RGCC+RG1
      C ENERGY LOSSES
      FLST=-5.*((BETAM*BETAM)+BS1)
      FLJC=5.*((K-L)*(1.-BETAM*BETAM-BS1))
      FLUF=UBL*WUTA
      FILE=(FLC1/2.)*((124/18-1.)*((B6S-BS1))
      RLST=FLST
      RLJC=5.*((K-L)*(1.-BETAM*BETAM-BS1))
      RLUF=FLUF
      RLEL=((K-L)/2.)*((1210/10-1.)*(BETAM*BETAM-BS1))
      C TOTAL ENERGY LOSSES
      TL=FLST+FLJC+FLUC+FILE+RLEL+FLUF+RLUF
      C SYSTEM ENERGY BALANCE
      C ENERGY LOSSES
      FLCC=TA*(EPS12)-EPS13)-FGCC
      FILEP=FILE+TA*(EPS14)-EPS15)
      RGCC=TA*(EPS18)-EPS19)-RGCC
      2FLP=2LEL+TA*(EPS110)-PS111)
      C TOTAL ENERGY LOSSES

```

1000L	- EFN	SOURCE STATEMENT	- JFN(S)	-	07/30/68	PAGE 17
$\text{TLP} = \text{FLST,RLST,FLUC,RLUC,FLUF,RLUF,FLCC,RLCC,FLP,RLFP}$ $\text{FTGP} = \text{TA,PIZ/(2.0,0)}$ RTGP,FTGP						
C C 101A: ENERGY GAINS						
$\text{TOP} = \text{FTGP,RTGP}$ $\text{WRITE}(19,119)$ TE,TE 134 $\text{WRITE}(5,123)$ TE,TE 135 $\text{WRITE}(5,121)$ TE,TE 135 $\text{WRITE}(5,122)$ FGCC,FTGP 136 $\text{WRITE}(5,123)$ FGLA,IGP 137 $\text{WRITE}(5,124)$ RGCC 137 $\text{WRITE}(5,125)$ RGU 138 $\text{WRITE}(5,126)$ FG,FGP 139 $\text{WRITE}(5,127)$ FLST,FLST 140 $\text{WRITE}(5,128)$ FLUC,FLUC 141 $\text{WRITE}(5,129)$ FLUC,FLUC 142 $\text{WRITE}(5,130)$ FLUF,FLUF 143 $\text{WRITE}(5,131)$ FLUF,FLUF 144 $\text{WRITE}(5,132)$ RLST,FLFLP 145 $\text{WRITE}(5,133)$ RLUC,RLST 146 $\text{WRITE}(5,134)$ RLUF,RLUC 147 $\text{WRITE}(5,135)$ RLUF,RLUF 148 $\text{WRITE}(5,136)$ RLCC 149 $\text{WRITE}(5,137)$ RLLP 150 $\text{WRITE}(5,138)$ TL,TLP 151 $\text{119 FORMAT}(11111/114,31) MEQIV ESCAPEMENT ENERGY BALANCE,6X,$ $\text{1 2M TOTAL SYSTEM ENERGY BALANCE,6/1}$ $\text{122 FORMAT}(111,20)M TOTAL ENERGY ,F12.6,5X,$ $\text{1 2M TOTAL ENERGY ,F12.6,6/1}$ $\text{121 FORMAT}(111,12)M ENERGY GAINS,25X,12M ENERGY GAINS,11$ $\text{122 FORMAT}(111,20)M FOR CATCHUP COL ,F12.6,5X,$ $\text{1 2M FOR INPUT ,F12.6,6/1}$ $\text{123 FORMAT}(111,20)M FOR IMPULSE ,F12.6,5X,$ $\text{1 2JOUR INPUT ,F12.6,6/1}$ $\text{124 FORMAT}(111,20)M FOR SIDE THRUST ,F12.6,6/1}$ $\text{125 FORMAT}(111,20)M FOR SIDE THRUST ,F12.6,6/1}$ $\text{126 FORMAT}(111,20)M TOTAL GAINS ,F12.6,5X,$ $\text{1 2M TOTAL GAINS ,F12.6,6/1}$ $\text{127 FORMAT}(111,13)M ENERGY LOSSES,24X,13M ENERGY LOSSES,11$ $\text{128 FORMAT}(111,20)M FOR SIDE THRUST ,F12.6,5X,$ $\text{1 2M FOR SIDE THRUST ,F12.6,6/1}$ $\text{129 FORMAT}(111,20)M FOR U,OCX COL ,F12.6,5X,$ $\text{1 2M FOR UNLOCK CJL ,X12.6,6/1}$ $\text{130 FORMAT}(111,20)M FOR UNLOCK FACTION ,F12.6,5X,$ $\text{1 2M FOR UP,OC, FACTION ,F12.6,6/1}$ $\text{131 FORMAT}(111,20)M FOR E LOSS ,F12.6,5X,$ $\text{1 2M FOR CJL,OC, FACTION ,F12.6,6/1}$ $\text{132 FORMAT}(111,20)M FOR UNLOCK CJL ,F12.6,5X,$ $\text{1 2M FOR L AND E LOSS ,F12.6,6/1}$ $\text{133 FORMAT}(111,20)M FOR UNLOCK RL ,F12.6,5X,$ $\text{1 2M REV SIDE THRUST ,F12.6,6/1}$ $\text{134 FORMAT}(111,20)M REV UNLOCK FACTION ,F12.6,5X,$ $\text{1 2M REV UNLOCK COL ,F12.6,6/1}$ $\text{135 FORMAT}(111,20)M REV L AND E LOSS ,F12.6,5X,$ $\text{1 2M REV UNLOCK FACTION ,F12.6,6/1}$						

10
S16FTC SIMPL

07/30/68

PAGE 21

```
SUBROUTINE SIMP(F,DELTAB,N,ERR,SUM,LP)
DIMENSION F(1971)
TN=V
LP=0
DF=F(5)-4.*F(4)+6.*F(3)-4.*F(2)+F(1)
SUM=Q
DO 7 J=1,N
  IF(J,NE.1,AND,J,NE.N) GO TO 5
  A=1.
  GO TO 7
5 IF(MOD(J,2).EQ.1) GO TO 6
  A=6.
  GO TO 7
6 A=2.
  GO TO 7
7 SUM=SUM+A*F(J)
  SUM=SUM*DELTAB/2.
E=ABSD(DELTAB)*N*DF/1800.
  R=ABSFERR*SUM)
  IF(E.LE.R) GO TO 10
  LP=1
10 CONTINUE
  RETURN
END
```

07/30/68

PAGE 2a

8
SIBFTC FUNC1

FUNCTION - EFN SOURCE STATEMENT - JFN(S) -

```
SUBROUTINE FUNCT(BETA,ICASE,II,12,X,Z,EPSS,R)
COMMON ORI,P,RPES,SN,QE,K,L,I0,I1,I2,I3,I4,MU,SM
REAL K,L,I0,I1,I2,I3,I4,MU,II,12
COSB,COSLBETAI
RID=1./ORI
ODR1=R10*ORI
X=(COSB-RID)/(ODR1-2.*COSB)
II=10*x*x*II
IF(ICASE.EQ.1) GO TO 10
YE=SQRT(LARS(R*QE*QE))
6 IF(ICASE.EQ.2) GO TO 5
5 Z=IS/YE)*SIN(SY*3.1415927*2./BN-EPSS)-1.
GO TO 23
23 Z=1.+(IS/YE)*SIN(EPSS)
13 20 I2=(II*x*x*Z*IE
14 RETURN
END
```

07/30/68

PAGE 25

07/30/68

PAGE 27

10
SIBFTC PH1

```

SUBROUTINE PHASE1(BETA0,BDOT0,EP50,EP5A,BETAF,TA,T,BDOTF,INP,BSTAR)
COMMON DR1,P,AP1,S,B1,QE,K1,L1,B1,L1,E,MU,SN
REAL K,L,B1,L1,IE,MU
FRIANG, SORT1,TAPE, S, S-2, APE, S-COS(ANG))
1 IF (P=1.0)NP=EQ.7) GO TO 5
      H=SURT(LK+L/1B)
      B01F=BETA0-BSTAR
      PH1=UPART(A(BD010)/(W*B01F))
      IF (NP=0.0)N=EQ.12) GO TO 7
      C
      A=SORT(B01F*B01F)/(8000T0/W)/(1800T0/W)
      SG=1.0-S
      RHO=P/2.-ATAN(SIN(BETA0)/(ORI-COS(BETA0)))
      IF (NP=EQ.11) GO TO 30
      R=RFRKHO
      ICASE=2
      GO TO 22
      30 ANG=P-RHO
      R=RFRKANG
      ICASE=3
      23 CALL FNCT1(BETA0,ICASE,DM,DN,X,Z,EP5B,R)
      DEFMX=Z
      EP5D=4BS(1DE8*BDOT0)
      CT=TA/(12.-IE)
      T=1EPS0/2.+SORT(1ABSTEPSD*EPSD/4.+CT*(EP5B-EP5A)))CT
      T1=PH1/W
      15 IF (T1.LE.T) GO TO 15
      HETF=SIGN(1A-COS(1W-T*PH10)*BSTAR,SG)
      BDOTF=SIGN(1A*W*SIN(1W-T*PH10),SG)
      GO TO 2
      15 T=1.1
      HETF=F-SIN(1NA0,SG)
      BDOTF=F-
      GO TO 10
      C
      C CALCULATION FOR PHASES 6 AND 12
      7 B01F=0.
      T=10/W
      GO TO 10
      C
      C CALCULATION FOR PHASES 1 AND 7
      5 T=SORT(1B/(W-L)).ARCCOS((BETAF-BSTAR)/(BETA0-BSTAR))
      10 RETURN

```

07/30/68

PAGE 30

5
SIBFTC PH2

PH2 - EFN SOURCE STATEMENT - IFN(S) -

PAGE 31

SUBROUTINE PHASE2(BETA0,BETAF,80D0,NO,ERR,MAX2,TAT,TP,ALARM,BST

IAR)

DIMENSION F(1001),M(1001),G(11)

COMD01,DR1,PARE,S,AN,QE,RL,18,LL,IE,MU,SN

REAL K,L,B,IL,IE,MU,I,KL

INTEGER ALARM

PI=3.1415927

RPE0=RPE/RPE

SS=SS*SS

KLE=KL

TF1NP=EQ+2) KL=K-L

RPE=RPE*SS

TAT=TA-MU

TRPE=S2*RPE

RD=1/DR1

OD=1/RIC*DL

PI2=PI/2.

ATG=2.*PI1*SN/BN

ALARM=2

N=10-1/2+1

IF(MOD(N,2).EQ.0) N=N+1

ITR=1

TN=1-1

DELTAB=(BETA0-BETA0)/TN

MUL=1

15 DELTF=DELTAB/4.

DU 10 J=1,N

TJ=J-2

BETAS=BETA0+TJ*DELTAB

IFI(J.EQ.1) BETAS=BETA0

DU 30 JK=1,5

TK=JK

NRA=ALUTASATK*ONELTF

COSB=COSB(TA)

RNJ=PI/2.*ATAN(SIN(BETA1)/(DR1-COSB))

X=(COSB-RD1)/(ODR1-2.*COSB)

IF1NP=EO/2.0R NP=EO.01 GO TO 7

IF1NP=EO.10 GOTO 5

RF=SURTAB1(RPE*SSQ-TRPE*COSS(RHO)))

Y=SQRTANS(RPE*RF-UE*QE))

EPSF=ARSIN(QE/RF)-ARSIN((RF*RF+SSQ-MPEQ)/(2.*SS*RF)))

Z=1.*S*SIN(IEPSF)/YE

GO TO 5

5 RR=SURTAB1(RPE*SSQ-TRPE*COSS(RHO)))

Y=SQRTANS(RR*EE*QE))

EPSR=ARSIP12(ANG-ARCSINE(RR)-ARSIN((RR*SSQ-RPEQ)/(2.*SS*RR)))

Z=(S*YE)*SIN(ANG-EPSR)-1.

5 T=1B*X*X*0.1*X*X*Z*0.1E

GU TO 3

7 T=1H*X*X*0.1L

U=0.1RPE*S*SIN(4*HO)/1RPE*U*SSQ-TRPE*S*COS(4*HO))

IP=1AH*J*U

FO=TF/KI

GO TO 2

3 F=H*X*Z*TA

43

44

39

31

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35

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38

PH2	- EEN	SOURCE STATEMENT	- IFN(S) -	07/30/68	PAGE 32
1		FO=FN/KL			
2	2	CLJK1FO			
		IFI(J,EO,1) GO TO 16			
3	30	CONTINUE			
		CALL SIMPLG,DELIF,S,ERR,SUM,LP)			
		H(IJ)*H(J-1)*2.*SUM			
		F(IJ)=SRT(ABS(IJ)/(H(IJ)-KL*(BETA*BETA-2.*BSTAR*(BETA-			
		1			59
		BEA0)+CO))			
		50 TO 15			
		16 CO=1.000TC*800D0			
		F(IJ)=BS11./B00D0)			
10	10	CONTINUE			
		CALL SIMP(F,DELTAB,N,ERR,SUM,LP)			
		I(FLP,NE,0) GO TO 45			
		IFI(IK,EQ,1) GO TO 45			
		IFI(ND(SUM1-SUM).GT.100.*ERR*ABS(SUM)) GO TO 45			
		SUM=(LS.*SUM-SUM1)/LS.			
		GO TO 20			
45	45	ITR=2			
		SUM1=SUM			
		DELTAB=DELTAB/2.			
		N=2*N1			
		IFI(4,GT,NMAX2) GO TO 17			
		50 TO 15			
		17 ALAK=1			
		20 T=ABS(SUM)			
		RETURN			
		END			

07/30/68

PAGE 35

80
SIGHTS

BITS - EFN SOURCE STATEMENT - IFN(S) - 07/30/68 PAGE 36

FUNCTION BETASIRHO

COMMON DR1

COMMON/ALAM/FLAG,2

FLAG,2

2=DR1* SIN(P/2.*RHO)

IF (Z,GT,1.) GOTO 1

Z1=Z

GOT 02

1 FLAG=1.

Z1=1.

2 BETAS=ARCSIN(Z1)-P/2.*RHO

RETURN

END

9

10
SIGHTS UNIC

FORTRAN - EFM SOURCE STATEMENT - IFM(LS) - 07/30/68 PAGE 39

```
SUBROUTINE UBICAFER,WMAN2,WMAN4,BETAF,BETAO,UB11
COMMON DATA,P,ARES,BN,DE,K,L,16,11,17,MU,SN
REAL K,L,16,11,17,MU,11,110
DIMENSION UB11(100)
PI=3.1415927
```

```
WMAN4,J
```

```
178,1
```

```
N1=1
```

```
N2=5
```

```
DELTA=BETAF-BETAO/4.
```

```
62 DO 13 J=N1,N2,N1
```

```
5=J-1
```

```
BE=DELTA-BETAO
```

```
CO=COS(BE)
```

```
SI=SIN(BE)
```

```
K=LCH+1/2*(DATA/11+DATA/1-2*CO)
```

```
9=M/P/2-ATAN(SV/IDR1-C0)
```

```
10 JBL(J)=K*PE*S*IN(RM)/MPE*2*S*2*PE*S*COS(RM)
```

```
CALL SUMPLB,DELTA,N2,ER,SUM,LP1
```

```
11 LP1=0,1 GO TO 45
```

```
12 LP1=0,11 GO TO 45
```

```
13 LM1=SUM1-SUM1,GT100,ERR=ABS(SUM1) GO TO 45
```

```
SUM1=SUM1/15.
```

```
GO TO 50
```

```
45 ITR=2
```

```
SUM1=SUM
```

```
14 ITR2,LT,WMAN2,GO TO 30
```

```
WMAN4,L
```

```
GO TO 50
```

```
50 DO 23 J=1,M2
```

```
JJ=N2-J+1
```

```
J2=2*J-1
```

```
23 U0,J2,UB(JJ)
```

```
N1=2
```

```
N2=2*M2-1
```

```
CALL DELTB/2,
```

```
GO TO 55
```

```
55 U0=SUM
```

```
RETURN
```

```
END
```



```
2  BETAI01-BETAS10M01011          35
  BETAI71-BETAS10M01711          36
  BETAI121-BETAS10M011011
C   CALCULATION OF ESCAPE WHEEL ANGULAR DISPLACEMENT          37
  EPS0=OMEGA-E(P1/2,A1011-(2.0543.174M)
EPS11=EPS0
EPS12=EPS11*OMEGA1,B1E1
EPS14=EPS11*GAMA,A2E1
EPS15=EPS0-P1/BN
EPS16=EPS15
EPS17=EPS15
EPS18=ABS(EPS11*OMEGA1,B1E1)
EPS19=ABS(EPS11*GAMA,A2E1)
EPS20=EPS0-2,P1/BN
EPS21=EPS111
RETURN
1000 JUMPA1 111,10H ASIN EROR  F10.6,161
END
```

HALCYC
SAMPLE DATA DECK

```
$DATA
ICOND=1,IGEOM=1,IRE=1685,AM=1286,0=-2937,RPP=-0061,0N=15,SN=3,
SDAT
GAMMA=52,
S=261,DR1=7,035,JB=10,ERR=1,E=6,REL=5,E=3,RELW=1,E=6,
40.22,VMAX=50,MAX2=100,MAX=20,A=92.9,IB=-3374,IL=3268,IE=3136,IL=13.33,
MU=3,A1=12,A2=15,A3=-40,JA=8,AMPL=50.75,90.120,150,210,270,330,
ND=11,
R1=186,R2=2019,IWRITE=5,BSTAR=1.55
6DAT
BSA1=2.5,IGEOM=1,UH1=38
SDAT
BSA2=3.25
```

CLOCK GEOMETRY

	RPP	RE	RP	R1	R2	Q	OMEGA
ACTUAL	0.0001200	0.1603000	0.1603011	0.1640000	0.2019000	0.0301047	0.1546664
EFFECTIVE	0.0001200	0.1746000	0.1603011	0.1840000	0.2080002	0.0301047	0.1546664

GAMMA SPAN FEETH S P
49.9999952 3.000000000 15.300000000 2.24100000106.68911362 0.12860000 0.04570030 7.0634999 41.09999905

PARAMETERS

K	L	16	IL	IE	MU	UBI	A1	A2
321.92000153	13.03000004	0.23740000	0.02680000	0.01360000	0.30000000	0.05243010	12.000000	16.300000

CONDITIONS

ERR	REL	RELM	NO	MAX	MAX2	IPARM	ICOND	IGEOM	IWRITE	BSYAN	A3
1.0E-03	5.0E-03	1.0E-06	11	50	20	1000	1	1	0	1.5035000E 00	-40.00000

EQUIL ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	505.488235	TOTAL ENERGY	505.488235
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	16.536185	FOR INPUT	44.31670
FUR IMPULSE	5.104334	REV INPUT	44.313670
REV CATCHUP COL	13.554356		
REV IMPULSE	4.281653		
TOTAL GAINS	39.576327	TOTAL GAINS	88.627340
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	14.398245	FOR SIDE THRUST	14.398245
FUR UNLOCK COL	0.575143	FOR UNLOCK COL	0.575143
FUR UNLOCK FACTION	3.328691	FOR UNLOCK FACTION	3.328691
FUR LAND E LOSS	1.356945	FOR CATCHUP COL	7.301238
REV SIDE THRUST	16.398245	FOR L AND E LOSS	15.438123
REV UNLOCK COL	0.345345	REV SIDE THRUST	14.398145
REV UNLOCK FACTION	3.328691	REV UNLOCK COL	0.345345
REV L AND E LOSS	1.865165	REV UNLOCK FACTION	3.328691
TOTAL LOSSES	39.576308	TOTAL LOSSES	88.527116

POSITION	BETA	RHO	EPSILON	PERIOD	800T
0	60.00000000E 00	46.39104920E 00	92.06066400E 01		5.00000000E-39
1	51.82112000E 00	46.39104920E 00	92.06066400E 01	34.36428920E-04	-46.27515900E 02
2	22.68198100E 00	49.75136930E 00	88.78014600E 01	42.93356300E-04	-85.93067000E 02
3	-10.77955100E 00	55.1618200E 00	23.95337300E 01	37.85536520E-04	-89.01815900E 02
4	-33.24688900E 00	58.37598630E 00	10.1167000E 01	27.20223500E-04	-75.72755300E 02
5	-49.27700450E 00	60.29806400E 00	-27.99333000E 01	20.29952200E-04	-5.36852500E 02
6	-56.88039700E 00	60.29806400E 00	-27.99333000E 01	36.9139200E-04	0.00000000E-43
7	-51.82112300E 00	60.29806400E 00	-27.99333000E 01	26.91457200E-04	36.07583100E 02
8	-27.68198100E 20	26.92774500E 00	-24.70824400E-01	46.32515600E-04	81.706189.00E 02
9	74.81981500E -21	52.11623600E 00	-78.51196500E-01	34.47536400E-04	9.2027471300E 02
10	33.24688500E 00	46.31315300E 00	-92.11602200E-01	30.33152130E-04	77.02781100E 02
11	51.50724300E 00	46.39104930E 00	-14.5993300E 00	28.95846800E-04	46.877455.00E 02
12	59.99999990E 00	46.39104920E 00	-14.7993300E 00	35.82275200E-04	5.00000000E-43

EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	789.825378	TOTAL ENERGY	789.825378
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	27.526091	FOR INPUT	78.453238
FOR IMPULSE	12.512527	REV INPUT	78.453238
REV CATCHUP COL	22.517523		
REV IMPULSE	10.267056		
TOTAL GAINS	72.803197	TOTAL GAINS	156.906475
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	22.758975	FOR SIDE THRUST	22.758975
FOR UNLOCK COL	1.948597	FOR UNLOCK COL	1.948597
FOR UNLOCK FACTION	5.992784	FOR UNLOCK FACTION	5.992784
FOR SIDE THRUST	6.150227	FOR CATCHUP COL	11.277114
REV SIDE THRUST	22.758975	FOR L AND E LOSS	31.082030
REV UNLOCK COL	1.568454	REV SIDE THRUST	22.758975
REV UNLOCK FACTION	5.992784	REV UNLOCK COL	5.992784
REV L AND E LOSS	5.932575	REV UNLOCK FACTION	5.992784
REV CATCHUP COL	10.064439	REV L AND E LOSS	63.762287
REV L AND E LOSS	63.762287	TOTAL LOSSES	156.906435
TOTAL LOSSES	72.803166		

POSITION	BETA	RHO	EPSILON	PERIOD	BOOT
0	75.00000000E+00	46.39104900E+00	92.0006666700E-01	52.41199692E+00	5.00000000E-39
1	51.02112400E+00	46.39104900E+00	92.00056400E-01	29.82618500E+00	-0.09754000E+02
2	22.68198700E+00	49.7516900E+00	88.76014500E-01	29.25897200E+00	-1.82353300E+03
3	-77.61421700E+01	54.61633420E+00	29.27483220E+01	27.25897200E+00	-11.34056300E+03
4	-33.24685900E+00	58.3756000E+00	10.1300300E+01	23.683957E+00	-13.2915300E+03
5	-50.44377200E+00	50.29864200E+00	32.993300E+01	15.06390300E+04	-86.52641800E+02
6	-71.96095100E+00	66.29864200E+00	-27.9933300E+01	51.22612910E+04	0.76.231000E+02
7	-51.02112300E+00	66.29864200E+00	-27.9933300E+01	48.68752100E+04	76.39731000E+02
8	-22.68198700E+00	56.92745200E+00	-26.77892600E+01	30.65068300E+04	1.6.66812000E+03
9	50.39535600E+01	52.51588800E+00	-74.75829100E+01	24.98441700E+04	11.39072500E+03
10	33.24685900E+00	48.31315300E+00	-99.13600200E+01	25.6227700E+04	1.7.43155500E+03
11	53.57601520E+01	46.39104900E+00	-14.79993300E+00	21.68125600E+04	81.35298800E+02
12	74.99999800E+00	46.39104900E+00	-14.79993300E+00	49.26621900E+04	0.7.33333300E+02

EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	1137.348541	TOTAL ENERGY	1137.348541
ENERGY GAINS		ENERGY GAINS	
FUR CATCHUP COL	40.992700	FOR INPUT	120.522517
FUR IMPULSE	21.822942	REV INPUT	120.522517
REV CATCHUP COL	33.536154		
REV IMPULSE	17.6253878		
TOTAL GAINS	113.612674	TOTAL GAINS	241.051035
ENERGY LOSSES		ENERGY LOSSES	
FUR SIDE THRUST	33.219990	FOR SIDE THRUST	33.019990
FUR UNLOCK COL	3.455041	FOR UNLOCK COL	3.405741
FUR UNLOCK FRICTION	9.352919	FUR UNLOCK FRICTION	9.052319
FUR UNLOCK F. LOSS	12.359861	FUR CATCHUP COL	16.267911
REV SIDE THRUST	33.219990	FUR L AND E LOSS	5.261201
REV UNLOCK COL	3.375390	REV SIDE THRUST	33.019990
REV UNLOCK FRICTION	9.322919	REV UNLOCK COL	3.073396
REV L AND E LOSS	10.927564	REV UNLOCK FRICTION	9.052919
		REV CATCHUP COL	14.753366
		REV L AND E LOSS	6.9.044294
TOTAL LOSSES	113.612676	TOTAL LOSSES	241.05123

POSITION	BETA	240	EPSILON	PERIOD	8031
0	90.30000000E+01	46.39104000E+01	92.01066400E-01	9.01000000E-39	9.01000000E-39
1	51.82112700E+00	46.39104000E+00	92.01066400E-01	61.99466200E-06	-11.29234100E+03
2	22.6819700E+00	49.75136600E+00	88.78014500E-01	23.45959500E-06	-13.2771100E+03
3	-63.23087100E-01	54.38366500E+00	31.87075900E-01	21.52719700E-06	-13.7531400E+03
4	-33.24685900E+01	58.37596000E+00	16.13603000E+01	25.192750E-06	-12.88119900E+03
5	-51.09117200E+00	60.29826000E+00	-27.99933300E+01	12.08923700E-06	-11.6182500E+03
6	-87.03913300E+00	65.29836000E+00	-27.99933300E+01	9.98652350E-06	-12.50000000E+03
7	-51.82112300E+00	62.29876000E+00	-27.99933300E+01	54.33111400E-06	1.96377000E+03
8	-27.68198730E+00	56.97745000E+01	-24.78826700E+01	23.81227000E-06	13.9150900E+03
9	38.96107300E-01	52.70270000E+00	-72.55735500E+01	19.78944500E-06	13.7257300E+03
10	33.26685900E+00	48.31315300E+00	-90.13502000E+01	21.8234100E-06	12.2265700E+03
11	54.50172800E+00	46.39104000E+00	-14.79933000E+00	17.46274900E-06	11.15831900E+03
12	89.99999800E+00	46.39104000E+00	-14.79933000E+00	58.57227100E-06	0.00000000E+00

EQUIV ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	221.952942	TOTAL ENERGY	2021.952942
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	74.396420	FOR INPUT	220.227663
FOR IMPULSE	65.969975	REV INPUT	220.227663
REV CATCHUP COL	61.701950		
REV IMPULSE	35.795331		
TOTAL GAINS	217.343674	TOTAL GAINS	456.466326
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	59.262428	FOR SIDE THRUST	59.242928
FOR UNLOCK COL	7.365899	FOR UNLOCK COL	7.366899
FOR UNLOCK FRICITION	17.142648	FOR UNLOCK FRICITION	17.142648
FOR LAND E LOSS	27.221261	FOR CATCHUP COL	29.126584
REV SIDE THRUST	59.242928	FOR LAND E LUSS	99.750744
REV UNLOCK COL	6.942295	REV SIDE THRUST	59.242928
REV UNLOCK FRICITION	17.142648	REV UNLOCK COL	6.942295
REV L AND E LOSS	23.542081	REV UNLOCK FRICITION	17.142648
REV CATCHUP COL		REV CATCHUP COL	26.865352
REV LAND E LOSS	133.692184		
TOTAL LOSSES	217.343682	TOTAL LOSSES	456.466303

POSITION	BETA	ALPHA	EPSILON	PERIOD	BOOT
0	12.0000000E+01	4.639104900E+00	92.00006600E-01	0.00000000E+00	0.00000000E+00
1	51.82112000E+00	4.639104900E+00	92.00006600E-01	72.66193900E-04	-16.64113500E+03
2	22.61497000E+00	4.9175136900E+00	68.78014500E-01	16.12789150E-04	-17.91386000E+03
3	-50.19244600E-01	54.17369800E+00	34.26369400E-01	15.30016320E-04	-18.38071700E+03
4	-13.246835900E+00	58.37596000E+00	10.13000500E-01	15.55835000E-04	-17.945211700E+03
5	-51.5623400E+00	6.629806400E+00	-27.99933000E-01	8.46277490E-05	-17.51582100E+03
6	-11.71529300E+01	6.029806400E+00	-27.99933000E-01	70.33788460E-04	0.00000000E+00
7	-51.82112300E+00	6.029806400E+00	-27.99933000E-01	70.89698450E-04	16.44138700E+03
8	-22.68198500E+00	5.693774500E+00	-24.77884400E-01	16.83010000E-04	-17.86741300E+03
9	28.74902000E+01	52.87073200E+02	-71.31514700E-01	16.13342100E-04	18.40134500E+03
10	33.2468500E+00	4.831315300E+00	-90.13600200E-01	16.68642710E-04	16.72591100E+03
11	55.31045200E+00	4.639104900E+00	-14.79993300E+00	12.67772400E-04	16.66645500E+03
12	12.0000000E+01	4.639104900E+00	-14.79993300E+00	69.45316450E-04	0.00000000E+00

EQUIL-EscapeMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	3159.301514	TOTAL ENERGY	3159.301514
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	117.905352	FOR INPUT	367.239288
FOR IMPULSE	70.925294	REV INPUT	367.239288
REV CATCHUP COL	97.8633983		
REV IMPULSE	59.767643		
TOTAL GAINS	352.542271	TOTAL GAINS	734.478577
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	93.267069	FOR SIDE THRUST	93.067369
FOR UNLOCK COL	12.46916	FOR UNLOCK COL	12.460716
FOR UNLOCK FRICTION	27.584096	FOR UNLOCK FRICTION	27.584296
FOR LAND E LOSS	66.9633296	FOR CATCHUP COL	45.766190
REV SIDE THRUST	93.267069	REV L AND E LOSS	163.249902
REV UNLOCK COL	11.946543	REV SIDE THRUST	93.067369
REV UNLOCK FRICTION	27.584096	REV UNLOCK COL	11.946543
REV L AND E LOSS	39.989317	REV UNLOCK FRICTION	27.584096
		REV CATCHUP COL	42.382738
		REV L AND E LOSS	217.070051
TOTAL LOSSES	352.542194	TOTAL LOSSES	734.478455

POSITION	ALFA	BETA	NUO	EPSILON	PERIOD	BDOT
0	15.0000000E+01	46.39104930E+00	92.00066400E-01	92.00066400E-01	78.62190320E-04	0.0000000E+00
1	51.82112900E+00	46.39104900E+00	92.00066400E-01	92.00066400E-01	13.09225107E-04	-21.6712990E+03
2	22.68198700E+03	49.75136930E+00	88.7114200E-01	88.7114200E-01	13.09225107E-04	-22.5762660E+03
3	-44.59817600E+01	54.0792600E+03	35.27229500E-01	35.27229500E-01	11.94729520E-04	-23.0547130E+03
4	-33.24685900E+00	58.3796000E+00	10.1362000E-01	10.1362000E-01	12.37637320E-04	-22.8775910E+03
5	-51.15546200E+00	60.29064200E+00	-27.99933200E-01	-27.99933200E-01	68.02447220E-05	-22.1450160E+03
6	-14.72493800E+01	60.29064200E+00	-7.99933200E-01	-7.99933200E-01	76.32717920E-06	-0.0000000E+00
7	-51.82112900E+03	60.29064200E+00	-27.99933200E-01	-27.99933200E-01	77.2979000E-04	-21.534510E+03
8	-22.041198700E+02	26.93745500E+00	-24.7882000E-01	-24.7882000E-01	13.12820620E-04	-22.54599600E+03
9	26.38019400E+01	22.94666300E+03	-20.621618200E-01	-20.621618200E-01	11.05664220E-04	23.06568200E+03
10	33.4685900E+03	48.31153200E+03	-49.136300E-01	-49.136300E-01	13.1421366300E-04	-22.9194500E+03
11	55.65130700E+00	46.39104900E+00	-14.79993100E+00	-14.79993100E+00	99.09141800E-05	21.84460300E+03
12	15.03000300E+01	46.39104930E+00	-14.79993100E+00	-14.79993100E+00	75.08223900E-04	0.0000000E+00

EQUIL-EscapeMENT ENERGY BALANCE

					TOTAL SYSTEM ENERGY BALANCE
TOTAL ENERGY	6192.231018	TOTAL ENERGY	6192.231018		
ENERGY GAINS		ENERGY GAINS			
FOR CATCHUP COL	233.943846	FOR INPUT	739.077934		
FOR IMPULSE	160.114922	REV INPUT	739.077934		
REV CATCHUP COL	194.535522				
REV IMPULSE	123.932155				
TOTAL GAINS	712.524361	TOTAL GAINS	1470.155869		
ENERGY LOSSES		ENERGY LOSSES			
FOR SIDE THRUST	183.510854	FOR SIDE THRUST	183.510854		
FOR UNLOCK COL	26.044229	FOR UNLOCK COL	26.044229		
FOR UNLOCK FRICTION	55.513659	FOR UNLOCK FRICTION	55.513659		
FOR L AND E LOSS	99.466151	FOR CATCHUP COL	90.309269		
REV SIDE THRUST	183.510854	FOR LAND E LOSS	314.361115		
REV UNLOCK COL	25.367059	REV SIDE THRUST	183.510854		
REV UNLOCK FRICTION	55.513659	REV UNLOCK COL	25.367059		
REV L AND E LOSS	83.581949	REV UNLOCK FRICTION	55.513659		
REV CATCHUP COL	80.068047	REV CATCHUP COL	80.068047		
REV L AND E LOSS	639.961201	REV L AND E LOSS	639.961201		
TOTAL LOSSES	712.524399	TOTAL LOSSES	1470.155823		

POSITION	BETA	AMO	EPSILON	PER 100	BODT
0	21.00020020E-01	46.39104900E-03	92.00006400E-01	0.00000000E-09	0.00000000E-09
1	51.02112900E-00	46.39104900E-00	92.00006400E-01	85.16486600E-04	-31.38475600E-03
2	22.03198700E-01	49.75136900E-03	68.79016000E-01	91.76976220E-05	-31.65788000E-03
3	-39.99844390E-01	54.00246430E-01	36.13295900E-01	83.536805500E-05	-32.57911520E-03
4	-33.24685900E-01	56.375464500E-00	10.13600000E-01	90.72352600E-05	-32.5854500E-03
5	-51.9512200E-01	62.298266300E-01	-27.9993100E-01	68.46331600E-05	-32.4694900E-03
6	-20.-420320E-01	60.-29816400E-00	-27.9993100E-01	83.02114330E-04	CJ.5C00050E-43
7	-51.-2112300E-00	60.-29816400E-00	-27.9993100E-01	84.24571220E-04	31.32285-0
8	-22.00198700E-01	56.93774500E-00	-27.77892200E-01	91.78056200E-05	31.87268900E-03
9	20.05262920E-01	53.0C25000E-00	-10.01614000E-01	77.43354100E-05	32.29137200E-03
10	33.24685900E-01	48.31315320E-01	-9.0.13627000E-01	96.32190700E-05	32.57636500E-03
11	55.03193100E-01	46.39104900E-00	-14.79993300E-03	70.38525700E-05	31.8167400E-03
12	21.00000000E-01	46.39104900E-00	-14.79993300E-00	82.59933900E-06	CC.0C00000E-06

EQUILY ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	10236.136719	TOTAL ENERGY	10236.136719
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	308.853271	FOR INPUT	1235.962112
FOR IMPULSE	271.213347	REV INPUT	1235.962112
REV CATCHUP COL	323.680918		
REV IMPULSE	209.552094		
TOTAL GAINS	1143.567623	TOTAL GAINS	2471.924225
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	304.375256	FOR SIDE THRUST	304.375256
FOR UNLOCK COL	44.156579	FOR UNLOCK COL	44.156579
FOR UNLOCK FRICTION	92.835649	FOR UNLOCK FRICTION	92.835649
FOR L AND E LOSS	169.327324	FOR CATCHUP COL	169.832554
REV SIDE THRUST	304.375256	FOR L AND E LOSS	562.70721
REV UNLOCK COL	63.316418	REV SIDE THRUST	304.375256
REV UNLOCK FRICTION	92.835649	REV UNLOCK COL	63.316418
REV L AND E LOSS	161.735456	REV UNLOCK FRICTION	92.835649
TOTAL LOSSES	1193.567673	REV CATCHUP COL	139.777294
		REV L AND E LOSS	737.679482
		TOTAL LOSSES	2471.923523

POSITION	BETA	240	EPSILON	PERIOD	800T
0	27.00000000E-21	46.39104930E-00	92.05056460E-01	5.00000000E-39	
1	51.82212900E-03	46.39104930E-00	92.02066450E-01	8.0.70899600E-04	-4.0.9093300E-03
2	22.64198700E-03	49.75136900E-03	88.78C14500E-01	70.01242750E-05	-4.1.1072500E-03
3	-38.0751300E-01	53.97178440E-02	36.47790900E-01	64.36622300E-05	-4.1.7C02500E-03
4	-33.24685900E-23	58.3759030E-03	10.13600350E-01	70.58834730E-05	-4.2.20527970E-03
5	-51.97605900E-03	60.24876330E-03	-27.99233300E-01	37.43926300E-05	-4.1.80600300E-03
6	-26.75183900E-01	60.298C620E-03	-27.99933300E-01	8.6.68556930E-04	-4.1.5C02500E-03
7	-51.8212333E-01	56.2986450E-03	-27.99933300E-01	8.6.68556930E-04	-4.1.5C02500E-03
8	-22.64198700E-03	26.9377500E-00	-26.778n240E-01	70.7.922420E-05	-4.1.1581400E-03
9	19.32036200E-01	53.02631600E-00	-69.7771700E-01	50.72151800E-05	4.1.71576500E-03
10	33.24685900E-03	48.311530E-00	-90.13600200E-01	75.05323170E-05	4.2.15756700E-03
11	56.04422800E-03	46.39104930E-00	-14.79993300E-00	56.41972500E-05	4.1.56970100E-03
12	26.99999990E-01	46.39104930E-00	-14.79993300E-00	86.3694100E-04	55.00000000E-03

EQUILIBRIUM ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	15291.319287	TOTAL ENERGY	15291.019287
ENERGY GAINS		ENERGY GAINS	
FUN CATCHUP COL	502.725098	FUN INPUT	1057.070036
FUN IMPULSE	410.501538	REV INPUT	1857.070036
REV CATCHUP COL	485.315205		
REV IMPULSE	317.252227		
TOTAL GAINS	1795.528047	TOTAL GAINS	3715.756773
ENERGY LOSSES		ENERGY LOSSES	
FUN SIDE THRUST	455.519238	FOR SIDE THRUST	455.636238
FUN UNLOCK COL	66.794765	FOR UNLOCK COL	66.794765
FUN UNLOCK FRICTION	139.569028	FOR UNLOCK FRICTION	139.569028
FUN LAND E LOSS	258.226762	FOR CATCHUP COL	224.367962
REV SIDE THRUST	455.534234	FOR LAND E LOSS	66.630205
REV UNLOCK COL	65.568106	REV SIDE THRUST	455.636238
REV UNLOCK FRICTION	139.569028	REV UNLOCK COL	65.636106
REV UNLOCK FRICTION	139.569028	REV UNLOCK FRICTION	139.569028
REV LAND E LOSS	214.359840	REV CATCHUP COL	224.51142
REV LAND E LOSS	214.359840	REV LAND E LOSS	1110.218246
TOTAL LOSSES	1795.527986	TOTAL LOSSES	3715.755798

POSITION	ALPHA	BETA	AMO	EPSILON	PERIOD	DDOT
2	33.0000000000E-01	46.391049900E-20	92.020066400E-01		0.000333000E-39	
1	51.0212903E-03	46.391049900E-01	92.020066400E-01		-50.3528230E-03	
2	22.401967000E-03	49.751363000E-03	86.7801450E-01		-50.343880200E-03	
3	-37.144528000E-01	53.956664000E-00	36.650525000E-01		-51.0251809E-03	
4	-33.26685903E-01	58.375963000E-01	13.1863C160E-01		-51.78561400E-03	
5	-52.309427600E-01	61.298304300E-01	-27.999333000E-01		-51.65975603E-03	
6	-32.77136403E-01	64.249264300E-01	-27.099333000E-01		-51.00111950E-04	
7	-51.421123300E-01	60.299266300E-01	-27.099333000E-01		-51.39333700E-03	
8	-22.601487000E-01	56.937741000E-01	-24.786240000E-01		-51.61615050E-03	
9	1.6.57784002E-01	52.038251000E-00	-69.658634000E-01		-51.42545700E-03	
10	31.26605903E-01	46.312151000E-01	-92.116762000E-01		-51.39420300E-03	
11	56.0522803E-01	46.341049000E-01	-14.199933000E-01		-51.22574600E-03	
12	32.99944003E-01	46.391049900E-01	-14.199933000E-01		-51.04055500E-03	

AMPLITUDE IN. 0.00000000	APPLIED TORQUE Dyne-Cm 0.00000000	PERIOD SEC 0.00000000	BEAT RATE SEATS/SEC 0.00000000	BEAT RATE ERROR PERCENT(REAL)
21.15821900E-01	40.03768120E-03	49.952996150E-00	00	-70.20436600E-03
37.43666100E-01	40.01901900E-03	49.98365700E-00	00	-87.61594930E-04
57.546669500E-01	40.002768820E-03	49.99651500E-00	00	16.96134120E-03
10.480129600E-01	39.99444120E-03	50.00144300E-00	00	26.81371070E-03
17.523186220E-01	40.00318480E-03	49.99451500E-00	00	22.96234220E-03
35.246637200E-01	40.00448540E-03	49.9393500E-00	00	11.79530533E-03
59.012644920E-01	40.00821200E-03	49.98966400E-00	00	32.54715520E-04
85.27161020E-01	40.01370430E-03	49.98662350E-00	00	-28.27357235E-04

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OUR CONVENT

NAME	SPAN	TEETH	SH	W	HT
GRANNA	3	0.020900209	15.300000000	0.23700000106	6.6911362
					2.12863000
					0.095700020
					0.781
					0.99999995

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EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	505.488235	TOTAL ENERGY	505.488235
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	17.132882	FOR INPUT	49.451113
FOR IMPULSE	7.769372	REV INPUT	49.451113
REV CATCHUP COL	13.524210		
REV IMPULSE	5.931126		
TOTAL GAINS	44.317686	TOTAL GAINS	98.902226
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	14.221484	FOR SIDE THRUST	14.221484
FOR UNLOCK COL	1.892350	FOR UNLOCK COL	1.892350
FOR UNLOCK FRICTION	3.714375	FOR UNLOCK FRICTION	3.714375
FOR LAND E LOSS	2.680835	FOR CATCHUP COL	8.257682
REV SIDE THRUST	14.221484	FOR L AND E LOSS	20.136531
REV UNLOCK COL	1.417418	REV SIDE THRUST	14.221484
REV UNLOCK FRICTION	3.714375	REV UNLOCK COL	1.417418
REV L AND S LOSS	2.655369	REV UNLOCK FRICTION	3.714375
		REV CATCHUP COL	6.766523
		REV L AND E LOSS	24.590013
TOTAL LOSSES	44.317686	TOTAL LOSSES	98.902226

POSITION	BETA	TAU	EPSILON	PERIOD	DDOT
0	60.0000000E+00	47.24389500E+00	92.05066400E-01		0.0000000E+00
1	42.5773300E+00	47.44389500E+00	92.05066400E-01	51.0813600E-04	0.0000000E+00
2	17.01126600E+00	50.60230720E+00	95.16826100E-01	33.21844900E-04	-6.01122900E-02
3	-13.68530900E+00	55.58618000E+00	33.62528000E-01	34.91639500E-04	-8.01974230E-02
4	-40.70283000E+00	59.24938000E+00	14.77186700E-01	35.49991150E-04	-62.76591900E-02
5	-55.92618000E+00	59.44821800E+00	17.99431300E-01	22.9431800E-04	-34.36156400E-02
6	-26.13790100E+00	59.44821800E+00	-27.99933000E-01	22.68295100E-04	0.0000000E+00
7	-42.57733000E+00	59.44821800E+00	-27.99933000E-01	44.73332200E-04	57.76889400E-02
8	-17.01126600E+00	26.08710720E+00	-31.15694000E-01	34.67212000E-04	-8.00346400E-02
9	10.46919000E+00	51.63292600E+00	-80.42768100E-01	31.23962200E-04	8.00346400E-02
10	40.70283000E+00	47.33973400E+00	-94.71863000E-01	37.43960100E-04	68.40922300E-02
11	55.42903000E+00	47.24389500E+00	-14.79993300E+00	27.79252200E-04	32.05099900E+02
12	59.99994900E+00	47.24389500E+00	-14.79993300E+00	25.36446500E-04	0.00000000E+00

EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY		769.825378	
ENERGY GAINS		TOTAL ENERGY	769.825378
FOR CATCHUP COL	28.195160	ENERGY GAINS	
FOR IMPULSE	15.017349	FOR INPUT	83.642816
REV CATCHUP COL	22.197739	REV INPUT	83.642816
REV IMPULSE	11.386766		
TOTAL GAINS	76.797013	TOTAL GAINS	167.2085631
ENERGY LOSSES		ENERGY LOSSES	
FUR SIDE THRUST	22.525129	FOR SIDE THRUST	22.525129
FUR UNLOCK COL	4.336527	FOR UNLOCK COL	4.336527
FUR UNLOCK FRICTION	6.282584	FOR UNLOCK FRICTION	6.282584
FUR LAND E LOSS	6.233616	FOR CATCHUP COL	12.824271
REV SIDE THRUST	22.525129	FOR L AND E LUSS	35.846146
KLV UNLOCK COL	3.447288	REV SIDE THRUST	22.525129
REV UNLOCK FRICTION	6.282584	REV UNLOCK COL	3.447288
REV LAND F LOSS	5.664104	REV UNLOCK FRICTION	6.282584
REV CATCHUP COL		REV CATCHUP COL	10.751219
REV L AND E LOSS		REV L AND E LOSS	42.764894
TOTAL LOSSES	76.796958	TOTAL LOSSES	167.205566

POSITION	BETA	RHO	EPSILON	PERIOD	BDOT
0	75.0000000E+00	47.24069500E+00	92.00066400E+01	3.0000000E-39	
1	42.5733000E+01	47.24069500E+01	92.00066400E+01	62.98325390E+04	-9.54317100E+02
2	17.01126490E+00	50.6220700E+00	95.15626100E+01	24.76396500E+04	-15.95857700E+03
3	-12.16658300E+01	25.32789730E+01	3.631683600E+01	26.25390000E+04	-11.12919900E+03
4	-40.02932300E+00	59.24938000E+00	14.77186700E+01	27.53859300E+04	-9.70289700E+02
5	-58.96280200E+01	59.544821800E+01	-27.99933300E+01	17.00233300E+06	-72.76104600E+02
6	-71.19348300E+01	59.44821800E+01	-27.99933300E+01	40.84176700E+04	0.70030300E+00
7	-42.57732600E+00	59.44921800E+01	-27.99933300E+01	58.78276500E+04	89.76575200E+02
8	-17.01106300E+00	56.08710700E+00	-31.15494600E+01	25.319614300E+03	-10.64314300E+03
9	91.56086100E+01	51.84663800E+00	-7.843559800E+01	23.52972800E+06	11.29147700E+03
10	40.0283200E+00	47.43973400E+00	-9.471869300E+01	29.53335900E+04	97.94757700E+02
11	56.82926100E+01	47.24089500E+00	-14.79993300E+00	21.03992200E+04	72.57390100E+02
12	-7.999999800E+00	47.24089500E+00	-14.79993300E+00	42.95153300E+04	0.50303000E+00

EQUIL ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	1137.346541	TOTAL ENERGY	1137.346541
ENERGY GAINS		ENERGY GAINS	
FUR CATCHUP COL	41.714478	FUR INPUT	125.736367
FUR IMPULSE	26.246118	REV INPUT	125.736367
ALV CATCHUP COL	32.799990		
REV IMPULSE	18.117592		
TOTAL GAINS	116.735514	TOTAL GAINS	251.472734
ENERGY LOSSES		ENERGY LOSSES	
FUR SIDE THRUST	32.735511	FUR SIDE THRUST	32.735511
FUR UNLOCK COL	6.557186	FUR UNLOCK COL	6.657186
FUR UNLOCK FRICTION	9.444317	FUR UNLOCK FRICTION	9.444317
FUR L AND E LOSS	12.625596	FUR CATCHUP COL	18.478847
REV SIDE THRUST	32.735511	REV L AND E LOSS	55.241392
REV UNLOCK COL	5.956632	REV SIDE THRUST	32.735511
REV UNLOCK FRICTION	9.444317	REV UNLOCK COL	5.956632
REV L AND E LOSS	9.361446	REV UNLOCK FRICTION	9.444317
		REV CATCHUP COL	15.675616
		REV L AND E LOSS	65.113346
TOTAL LOSSES	116.735515	TOTAL LOSSES	251.472719

POSITION	BETA	TAU0	EPSILON	PERIOD	BOOT
0	90.0000000E+00	47.2400000E+00	92.0000000E+01	70.05220100E+06	5.70C90300E-39
1	42.5773300E+00	47.2400000E+00	92.0000000E+01	70.05220100E+06	-12.0742800E+03
2	17.01106400E+00	50.6020000E+00	95.16626100E+01	19.94566400E+06	-13.2951200E+03
3	-11.38614900E+00	55.20315100E+00	37.19343030E+01	21.15648700E+06	-13.51275300E+03
4	-60.70232000E+00	59.24938200E+00	16.77166721-01	22.69550700E+06	-12.21525300E+03
5	-60.25332000E+00	59.44492100E+00	-27.93933000E+01	13.64802450E+06	-10.4640500E+03
6	-86.24638000E+00	59.44821000E+00	-27.93923300E+01	51.63016200E+06	-10.5000000E+03
7	-42.57722000E+00	59.44821000E+00	-27.93933300E+01	66.82333900E+06	11.77629900E+03
8	-17.31105300E+00	55.08710000E+00	-31.1544620-01	20.22114400E+06	12.21366900E+03
9	85.00867300E+01	21.95052200E+00	-77.42516500E+01	18.96692200E+06	12.63599000E+03
10	40.73283200E+00	47.44397300E+00	-94.77145900E+01	26.45651400E+06	12.77380100E+03
11	60.35605000E+00	47.24000000E+00	-14.79793300E+00	17.04117000E+06	10.62238100E+03
12	-69.99999900E+00	47.24000000E+00	-14.74933000E+00	53.48229800E+06	00.CC000000E+00

ENEMY ESCAPEMENT ENERGY BALANCE			TOTAL SYSTEM ENERGY BALANCE		
TOTAL ENERGY			TOTAL ENERGY		
2321.352942			2321.952042		
ENERGY GAINS			ENERGY GAINS		
FOR CATCHUP COL	76.188705		FOR INPUT	233.541790	
FUN IMPULSE	47.276168		REV INPUT	233.541790	
REV CATCHUP COL	59.966719				
REV IMPULSE	35.516127				
TOTAL GAINS	218.347357		TOTAL GAINS	467.083591	
ENERGY LOSSES			ENERGY LOSSES		
FOR SIDE THRUST	58.846689		FOR SIDE THRUST	58.846689	
FOR UNLOCK COL	13.327937		FOR UNLOCK COL	13.327937	
FOR UNLOCK FRICTION	17.541854		FOR UNLOCK FRICTION	17.541854	
FOR L AND E LOSS	21.727154		FOR CATCHUP COL	32.997221	
REV SIDE THRUST	59.946689		FOR L AND E LOSS	104.496759	
REV UNLOCK COL	12.613750		REV SIDE THRUST	58.846689	
REV UNLOCK FRICTION	17.541854		REV UNLOCK COL	12.613750	
REV L AND E LOSS	16.721954		REV UNLOCK FRICTION	17.541854	
REV CATCHUP COL	28.308152		REV CATCHUP COL	28.308152	
REV L AND E LOSS	122.292263		REV L AND E LOSS	122.292263	
TOTAL LOSSES	218.947475		TOTAL LOSSES	467.083514	

POSITION	ALPHA	BETA	240	EPSILON	PERIOD	B001
0	12.00000000E+01	47.24089500E+00	92.03066400E+01			0.00000000E+00
1	42.57733050E+03	47.24089500E+00	92.03066400E+01	78.27963700E-04		-17.13329100E+03
2	17.01136500E+02	50.6C270700E+00	95.16261000E+01	14.48366700E-04		-17.93817000E+03
3	-10.64+313205E+03	25.298447500E+00	39.06362200E+01	15.34068630E-04		-16.22123400E+03
4	-40.70283200E+02	29.24938100E+02	14.77185700E+01	16.86609120E-04		-17.45850100E+03
5	-61.35721000E+03	59.446921800E+03	227.99933300E+01	98.7742300E-05		-16.1492800E+03
6	-11.63459200E+01	59.446921800E+00	-27.99933300E+01	64.2745700E-04		0.00000000E+00
7	-42.57732000E+02	59.446921800E+00	-27.99933300E+01	76.02357300E-04		16.95187000E+03
8	-17.01136500E+02	26.5H1C700E+00	-31.15614000E+01	14.55649100E-04		17.4345600E+03
9	79.88+311000E+01	52.5493400E+00	-76.47130400E+01	13.76533200E+04		1b.3u604000E+03
10	49.70283200E+02	7.6397300E+00	-94.77196900E+01	16.2276900E-04		17.6337300E+03
11	61.73581500E+00	4.24089500E+00	-14.79933000E+00	12.42748220E-04		16.0964500E+03
12	12.00000000E+01	47.24089500E+00	-14.79933000E+00	05.75+46900E-04		05.0C000000E+00

EQUIV ESCAPEMENT ENERGY BALANCE

	TOTAL ENERGY	TOTAL ENERGY	TOTAL SYSTEM ENERGY BALANCE
ENERGY GAINS	3159.301514	3159.301514	
FOR CATCHUP COL	120.646362	120.646362	
FOR IMPULSE	72.542492	72.542492	
REV CATCHUP COL	94.798309	94.798309	
REV IMPULSE	58.172612	58.172612	
TOTAL GAINS	350.457775	350.457775	
ENERGY LOSSES			TOTAL GAINS
FOR SIDE THRUST	92.569426	92.569426	745.594032
FOR UNLOCK COL	21.046662	21.046662	
FOR UNLOCK FRICTION	28.201549	28.201549	
REV LAND S LOSS	36.385241	36.385241	
REV SIDE THRUST	92.569426	92.569426	
REV UNLOCK COL	20.168771	20.168771	
REV UNLOCK FRICTION	28.201549	28.201549	
REV LAND S LOSS	30.796892	30.796892	
REV CATCHUP COL	64.655225	64.655225	
REV LAND E LOSS	196.045532	196.045532	
TOTAL LOSSES	350.357806	TOTAL LOSSES	745.5940325

POSITION

POSITION	BETA	ALPHA	EPSILON	PERIOD	B001
0	15.00000000E+01	7.24369520E+00	92.05066406E-01	82.90463770E-06	3.00000000E-39
1	42.57733000E+00	47.24369520E+00	92.05066406E-01	11.41562510E-01	-22.56176000E-03
2	17.01136430E+00	50.620070E+00	95.15625100E-01	12.07666700E-04	-22.90282300E-03
3	-10.31323720E+00	25.53126300E+00	39.65771800E-01	13.42354450E-05	-22.48716300E-03
4	-40.73232000E+00	59.44821800E+00	14.71186700E-01	17.72057700E-05	-21.48971900E-03
5	-61.15386200E+00	59.44821800E+00	-27.99933300E-01	71.54473500E-04	-2.00000000E-40
6	-14.64449700E+01	59.44821800E+00	-27.99933300E-01	61.23255000E-04	21.69425000E-03
7	-42.57732600E+01	59.44821800E+00	-27.99933300E-01	11.156450E-01	22.56139600E-03
8	-17.31120300E+01	56.64710750E+00	-31.156450E-01	11.437400E-04	-22.90887900E-04
9	76.17971620E+01	52.936920E+00	-76.0-727300E-01	10.86017700E-06	22.90887900E-03
10	40.70283220E+00	57.337540E+00	-96.77136300E-01	14.53567700E-05	-22.48716300E-03
11	62.11752900E+00	57.24049500E+00	-16.79493300E+00	98.10164200E-05	21.37852200E-03
12	15.00000000E+01	67.24049500E+00	-16.79493300E+00	72.76598900E-04	0.00000000E-40

EQUIL_ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	6192.231018	TOTAL ENERGY	6192.231018
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	239.593445	FOR INPUT	745.606384
FOR IMPULSE	157.894673	REV INPUT	745.606384
REV CATCHUP COL	180.280884		
REV IMPULSE	110.502611		
TOTAL GAINS	730.351593	TOTAL GAINS	1491.212769
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	182.836170	FOR SIDE THRUST	182.836170
FOR UNLOCK COL	44.775876	FOR UNLOCK COL	44.775876
FOR UNLOCK FRICTION	56.034026	FOR UNLOCK FRICTION	56.034026
FOR LAND E LOSS	75.772730	FOR CATCHUP COL	102.033134
REV SIDE THRUST	182.836170	FOR LAND E LOSS	341.526733
REV UNLOCK COL	43.292523	REV SIDE THRUST	182.836170
REV UNLOCK FRICTION	56.034026	REV UNLOCK COL	43.292523
REV LAND E LOSS	62.830063	REV UNLOCK FRICTION	56.004026
		REV CATCHUP COL	88.351158
		REV LAND E LOSS	393.552964
TOTAL LOSSES	730.351593	TOTAL LOSSES	1491.212762

POSITION	BETA	ALPHA	EPSILON	PERIOD	B001
0	21.00000000E-01	47.24369500E-00	92.030466400E-01	88.20766220E-04	0.00000000E-39
1	42.57733000E-00	47.24089500E-00	92.030466400E-01	80.45016100E-05	-31.5443100E-03
2	17.01106430E-00	50.63200793E-00	95.15026100E-01	80.45016100E-05	-31.78465100E-03
3	-10.03092600E-00	54.98544400E-00	63.16391100E-01	84.9477400E-05	-32.24118300E-03
4	-40.70283200E-00	29.24198000E-00	14.77186700E-01	95.28910000E-05	-32.30277700E-03
5	-62.19200800E-00	39.44821800E-00	-27.99933100E-01	54.70428500E-05	-31.54816400E-03
6	-20.66375900E-01	59.44911800E-00	-27.99933100E-01	79.65306820E-06	0.50000000E-02
7	-42.57732630E-00	29.44821800E-00	-27.99933100E-01	86.49907300E-06	31.51610400E-03
8	-17.01106300E-00	26.48710700E-00	-31.54943000E-01	86.37742600E-05	31.63336500E-03
9	73.89020700E-01	52.13116800E-00	-75.666888000E-01	76.46348000E-05	32.2891200E-03
10	40.323209E-00	47.43913420E-00	-94.716600E-01	13.34149532E-05	32.32626700E-03
11	62.60382600E-00	47.24089500E-00	-16.79993200E-00	69.23774200E-05	31.46369700E-03
12	21.03300300E-01	47.24089500E-00	-14.79993200E-00	80.55210100E-04	0.00000000E-40

EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	10236.136719	TOTAL ENERGY	10236.136719
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	398.61380	FOR INPUT	1244.127029
FOR IMPULSE	265.541529	REV INPUT	1244.127229
REV CATCHUP COL	313.268066		
REV IMPULSE	199.381693		
TOTAL GAINS	1176.905853	TOTAL GAINS	2488.224059
ENERGY LOSSES		ENERGY LOSSES	
FU SIDE THRUST	303.530116	FOR SIDE THRUST	303.530116
FOR UNLOCK COL	75.270826	FOR UNLOCK COL	75.270826
FOR UNLOCK FRICTION	93.448935	FOR UNLOCK FRICTION	93.448935
FOR L AND E LOSS	128.597137	FOR CATCHUP COL	169.251283
REV SIDE THRUST	303.530116	FOR L AND E LOSS	572.027191
REV UNLOCK COL	73.467016	REV SIDE THRUST	303.530116
REV UNLOCK FRICTION	93.448935	REV UNLOCK COL	73.467076
REV L AND E LOSS	105.520955	REV UNLOCK FRICTION	93.448935
REV CATCHUP COL		REV CATCHUP COL	166.809212
REV L AND E LOSS		REV L AND E LOSS	167.400658
TOTAL LOSSES	1176.906067	TOTAL LOSSES	2488.224123

POSITION	BETA	ALPHA	EPSILON	PERIOD	BEST
0	27.0000000E+01	47.2408930E+00	92.0006640E-01	91.0518850E-04	6.0000000E-39
1	42.573000E+01	47.2408950E+00	92.0006640E-01	91.0518850E-04	-4.0.9623600E+03
2	17.01126400E+00	50.60200700E+00	95.16626100E-01	62.146992300E-05	-4.0.99302600E+03
3	-99.16456595E-01	58.96740450E+00	40.99383500E-01	65.672572200E-05	-4.1.56753700E+03
4	-40.70232200E+00	59.224938300E+00	1.771867000E-01	74.107364370E-05	-21.98212700E+03
5	-62.34612200E+01	59.444821800E+01	-27.99933200E-01	62.270157000E-05	-41.4370400E+03
6	-26.6828400E+01	59.444821800E+00	-27.99933300E-01	84.C8131100E-04	03.CDC0300E-43
7	-42.57712500E+00	54.44821800E+00	-27.99933300E-01	90.117046400E-04	40.9925900E+03
8	-17.01126400E+01	56.08710700E+00	-31.5474200E-01	62.09715200E-05	-21.8625900E+03
9	72.96671600E+01	52.14623800E+00	-75.54605300E-01	59.11214100E-05	41.6069200E+03
10	40.7028200E+00	47.43973400E+00	-94.77185903E-01	80.26853700E-05	41.94670800E+03
11	62.997162200E+01	47.24089300E+00	-14.799933200E+00	53.54388400E-05	41.27846600E+03
12	26.999999950E+01	47.24089500E+00	-14.799933000E+00	84.790753300E-04	03.CDC0300E-43

EQUIL ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	15291.019287	TOTAL ENERGY	15291.019287
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	597.719116	FOR INPUT	1058.353134
FOR IMPULSE	400.572036	REV INPUT	1068.353134
REV CATCHUP COL	469.763916		
REV IMPULSE	300.566465		
TOTAL GAINS	1768.620117	TOTAL GAINS	3736.706268
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	454.653091	FOR SIDE THRUST	454.653091
FOR UNLOCK COL	113.380516	FOR UNLOCK COL	113.380516
FOR UNLOCK FRICTION	140.335318	FOR UNLOCK FRICTION	140.335318
FOR L AND E LOSS	194.828189	FOR CATCHUP COL	253.417572
REV SIDE THRUST	454.653091	REV L AND E LOSS	860.759582
REV UNLOCK COL	111.314846	REV SIDE THRUST	454.653091
REV UNLOCK FRICTION	140.335318	REV UNLOCK COL	111.314846
REV L AND E LOSS	159.109571	REV UNLOCK FRICTION	140.335318
REV CATCHUP COL	225.066668	REV CATCHUP COL	225.066668
REV L AND E LOSS	987.846370	REV L AND E LOSS	987.846370
TOTAL LOSSES	1768.620529	TOTAL LOSSES	3736.706451

POSITION	BETA	MO	EPSILON	PERIOD	BOOT
0	33.00000000E+01	47.24019500E+00	92.00066400E+01	92.00066400E+01	0.0000000E+00
1	42.577300E+00	47.24089290E+00	92.00056400E+01	92.00056400E+01	50.3281500E+03
2	17.01106400E+02	50.662000100E+02	95.15626100E+01	95.15626100E+01	-50.1951820E+03
3	-98.5872900E+01	56.95810090E+00	40.48972100E+01	53.53836350E+01	-50.86940900E+03
4	-40.70282200E+00	59.24938000E+00	14.771867635E+01	60.54733550E+01	-51.02239730E+03
5	-62.41359200E+02	59.44921000E+02	-27.99933100E+01	36.66163300E+01	-51.1577400E+03
6	-32.71174500E+01	59.44921000E+01	-27.99933100E+01	86.87837500E+01	0.0000000E+00
7	-42.5773600E+00	59.44921000E+00	-27.99933100E+01	92.08638600E+01	50.4622000E+03
8	-17.01106300E+00	56.06710700E+00	-31.16696000E+01	50.614345430E+01	50.32109400E+03
9	72.49910800E+01	52.15382200E+00	-75.46139000E+01	48.19632200E+01	50.92433500E+03
10	40.70281200E+03	47.43973500E+00	-94.77186900E+01	65.58081700E+01	51.1577400E+03
11	63.09340000E+01	47.24089500E+00	-14.79933000E+01	43.6741800E+01	50.9735300E+03
12	32.99999900E+01	47.24089500E+00	-16.79933000E+01	87.46236900E+01	0.0000000E+00

AMPLITUDE	APPLIED TORQUE , DYNME-CM	PERIOD SEC	BEAT RATE BEATS/SEC	BEAT RATE ERROR PERCENTILE.1
60.00000E-00	29.0111200E-01	40.171823300E-03	49.78614200E-00	-36.455537000E-02
74.00000E-00	39.93650210E-01	40.05370700E-03	49.91295700E-00	-70.7349900E-03
93.03531100E-00	60.03469200E-01	40.01220300E-03	49.98674500E-00	32.90641300E-03
124.032312E-01	11.15279901E-02	39.98262200E-03	50.01342600E-00	90.30911500E-03
15.00000E-01	7.799740CE-02	39.985910300E-03	50.016480E-00	96.19326100E-03
21.00000E-01	55.6130E-02	39.99174300E-03	50.016480E-00	84.09490300E-03
27.00000E-01	59.4264900E-02	39.995994200E-03	50.016480E-00	70.95639100E-03
34.00000E-01	60.23729000E-02	40.000103000E-03	49.998105000E-00	60.835605000E-03

108

CLOCK GEOMETRY

	RPP	RE	RP	R2	R3	0	0	0	0
ACTUAL	0.0001300	0.1605000	0.1603011	0.1640000	0.2019000	0.0101047	0.5466664	0.0000000	57.2000056
EFFECTIVE	0.0001300	0.1746000	0.1603011	0.1640000	0.2000000	0.0201047	0.1566664	0.0000000	57.2000056

GAMMA SPAN TEETH 5 0.23700000106.68911362 0.12862000 0.39570000 7.0639999 41.9999995

49.39999952 2.00000000 15.02000000 0.23700000106.68911362 0.12862000 0.39570000 7.0639999 41.9999995

PARAMETERS

	10	11	12	13	14	15	16	17	18
	321.33000153	13.030000004	0.337400000	0.026800000	0.013600000	0.30000000	0.03243811	12.000000	16.000000

CONDITIONS

ERA	REL	R3LM	NO	MAX	MAX2	IPARM	ICOND	ICOND	INITE	BSYAN	BSYAN	0
1.0E-05	5.3E-03	1.3E-06	11	50	20	100	0	1	1	0	3.200000000	-40.000000

EDJW ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	505.488235	TOTAL ENERGY	575.488235
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	16.2233402	FOR INPUT	47.070423
FOR IMPULSE	7.296624	REV INPUT	47.070423
REV CATCHUP COL	12.98076		
REV IMPULSE	5.221134		
TOTAL GAINS	42.279166	TOTAL GAINS	94.140846
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	13.645421	FOR SIDE THRUST	13.645421
FOR UNLOCK COL	1.892350	FOR UNLOCK COL	1.892350
FOR UNLOCK FRICTION	3.535556	FOR UNLOCK FRICTION	3.535556
FOR LAND E LOSS	1.991836	FOR CATCHUP COL	8.004958
REV SIDE THRUST	13.665421	REV E LOSS	10.68760
REV UNLOCK COL	1.137898	REV SIDE THRUST	13.645421
REV UNLOCK FRICTION	3.535556	REV UNLOCK COL	1.137898
REV L AND E LOSS	2.055369	REV UNLOCK FRICTION	3.535556
REV CATCHUP COL	6.004953	REV L AND E LOSS	23.534029
TOTAL LOSSES	42.379176	TOTAL LOSSES	94.140852

POSITION	BETA	THETA	EPSILON	PERIOD	B001
0	60.00000000E+00	47.2408500E+00	92.0306640E-01		0.00000000E+00
1	42.5773200E+00	47.2408500E+00	92.0306640E-01		-65.29612600E+02
2	17.01106400E+00	50.6200150E+00	95.1662610E+01		-84.5895400E+02
3	-13.82075500E+00	55.5912600E+00	33.37367400E+01		-84.23266700E+02
4	-40.7383100E+00	29.2493000E+00	14.7146700E+01		-57.3406100E+02
5	-57.36617300E+00	59.44821800E+00	-27.99933300E+01		-27.746100E+02
6	-53.7328700E+00	59.44821800E+00	-27.99933300E+01		0.00000000E+00
7	-42.5773200E+00	59.44821800E+00	-27.99933300E+01		-65.29612600E+02
8	-17.01106330E+00	56.08710700E+00	-31.16496300E+01		-84.5895400E+02
9	10.51169300E+00	51.82596900E+00	-83.42499600E+01		-87.61761200E+02
10	40.723200E+00	47.43913400E+00	-94.77186900E+01		-67.57477700E+02
11	55.56565200E+00	47.2408500E+00	-14.79993300E+00		28.4196300E+02
12	59.99999900E+00	47.2408500E+00	-14.79993300E+00		25.32825800E+02

EQUILIBRIUM ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	789.825378	TOTAL ENERGY	789.825378
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	27.143417	FOR INPUT	60.617241
FOR IMPULSE	14.380539	REV INPUT	60.617041
REV CATCHUP COL	21.447655		
REV IMPULSE	10.73980		
TOTAL GAINS	73.945590	TOTAL GAINS	161.234081
ENERGY LOSSES		ENERGY LOSSES	
FUR SIDE THRUST	21.816526	FOR SIDE THRUST	21.816526
FUR UNLOCK COL	4.035527	FOR UNLOCK COL	4.035527
FUR UNLOCK FRICTION	6.055311	FUR UNLOCK FRICTION	6.055311
FUR LAND E LOSS	5.410180	FUR CATCHUP COL	12.45695
REV SIDE THRUST	21.816526	FUR LAND E LOSS	34.144243
REV UNLOCK COL	3.0391093	REV SIDE THRUST	21.816526
REV UNLOCK FRICTION	6.055311	REV UNLOCK COL	3.0391090
REV LAND E LOSS	5.566104	REV UNLOCK FRICTION	6.055311
REV CATCHUP COL	12.31053	REV CATCHUP COL	12.31053
REV LAND E LOSS	41.422774	TOTAL LOSSES	161.234055
TOTAL LOSSES	73.945573	TOTAL LOSSES	161.234055

POSITION	BETA	AMO	EPSILON	PERIOD	BDOT
0	75.00000000	47.24089500E-00	92.00066600E-01	63.25463520E-04	0.00030000E-39
1	42.51733000	47.24089500E-00	92.00066600E-01	63.25463520E-04	-92.8348200E-02
2	17.01106400	50.6200700E-00	95.16626100E-01	25.06516500E-04	-1.8.838100E-03
3	-12.24448700	55.34529800E-00	36.17757100E-01	26.77357400E-04	-1.6.8936700E-03
4	-40.70283200	30.59249800E-00	14.77186700E-01	28.28590300E-04	-9.7.2630300E-02
5	-60.97121800	39.44821800E-00	-27.99933000E-01	17.42292600E-04	-67.94387100E-02
6	-68.70347000	59.44821800E-00	-27.99933000E-01	37.29241600E-04	0.00030000E-03
7	-42.57732600	30.5944821800E-00	-27.99933000E-01	56.58098400E-04	85.91278100E-02
8	-17.01106300	26.08710700E-00	-31.16474600E-01	26.11612700E-04	1.6.6506600E-03
9	91.56422700E-01	21.66430200E-00	-78.43689100E-01	23.96755500E-04	1.1.12365400E-04
10	40.70283200	47.43913400E-00	-97.77185000E-01	29.02769300E-04	96.93071700E-02
11	58.92261700	47.24089500E-00	-16.79993300E-00	21.63215500E-04	71.6928600E-02
12	74.99999600	47.24089500E-00	-14.79993300E-00	43.17510200E-04	0.00030000E-03

EQUILY ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	1137.340541	TOTAL ENERGY	1137.340541
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	62.670139	FOR INPUT	122.067507
FOR IMPULSE	23.254123	REV INPUT	122.067507
REV CATCHUP COL	31.883835		
REV IMPULSE	17.529523		
TOTAL GAINS	113.266619	TOTAL GAINS	244.135014
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	31.869386	FOR SIDE THRUST	31.869386
FOR UNLOCK COL	6.657186	FOR UNLOCK COL	6.657186
FOR UNLOCK FRICTION	9.156741	FOR UNLOCK FRICTION	9.168741
FOR LAND E LOSS	9.567973	FOR CATCHUP COL	16.055266
REV SIDE THRUST	31.869386	FOR LAND E LOSS	53.176286
REV UNLOCK COL	5.523766	REV SIDE THRUST	31.869386
REV UNLOCK FRICTION	9.168741	REV UNLOCK COL	5.523766
REV LAND E LOSS	9.341446	REV UNLOCK FRICTION	9.168741
		REV CATCHUP COL	15.160470
		REV LAND E LOSS	63.495977
TOTAL LOSSES	113.266619	TOTAL LOSSES	244.134798

POSITION	BETA	THETA	EPSILON	PERIOD	PERIOD	PERIOD	PERIOD
0	90.0000000E+00	67.24089500E+00	92.00000000E-01	70.50000000E-04	7.00000000E-39		
1	42.57733200E+00	47.24089500E+00	92.00000000E-01	70.50000000E-04	-11.96106500E+03		
2	17.01106400E+00	50.62607000E+00	95.16626100E-01	12.15637200E-04	-15.13950200E+03		
3	-11.43431620E+00	55.211053200E+00	37.63212500E-01	21.48810720E-04	-13.29133800E+03		
4	-40.73283200E+00	59.24338000E+00	14.71867100E-01	23.14242200E-04	-11.88839500E+03		
5	-62.3770100E+00	59.44021600E+00	27.99933000E-01	13.89968100E-04	-10.08771400E+03		
6	-83.84256830E+00	59.44821600E+00	27.99933000E-01	48.74361000E-04	0.30303000E-40		
7	-42.37732600E+00	59.44421600E+00	27.99933000E-01	65.26759800E-04	11.46748200E+03		
8	-17.01106100E+00	36.04710730E+00	-31.15496300E-01	20.45258400E-04	12.40255400E+03		
9	84.92632900E+01	51.95165700E+00	77.41243600E-01	19.26546400E-04	15.4684200E+03		
10	43.73283200E+00	47.43973400E+00	-94.77117830E-01	24.73117830E-04	12.78552700E+03		
11	60.44637900E+00	47.24089500E+00	-14.79993300E+00	17.27926660E-04	10.32662700E+03		
12	89.99999800E+00	47.24089500E+00	-14.79993300E+00	53.700948100E-04	0.30000000E-40		

EQUIN ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY		2021.92942	
ENERGY GAINS		ENERGY GAINS	2021.92942
FOR CATCHUP COL	74.566996	FOR INPUT	228.588223
FOR IMPULSE	46.190254	REV INPUT	228.588223
REV CATCHUP COL	58.632996		
REV IMPULSE	24.386567		
TOTAL GAINS	214.259812	TOTAL GAINS	457.176445
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	57.580341	FOR SIDE THRUST	57.680341
FOR UNLOCK COL	13.27957	FOR UNLOCK COL	13.37957
FOR UNLOCK FRICTION	17.169731	FOR UNLOCK FRICTION	17.169731
FOR LAND E LOSS	20.101175	FOR CATCHUP COL	32.454181
KEY SIDE THRUST	57.580341	FOR LAND E LOSS	152.176115
REV UNLOCK COL	11.027555	REV SIDE THRUST	57.680341
REV UNLOCK FRICTION	17.169731	REV UNLOCK COL	11.627555
REV LAND E LOSS	16.701954	REV UNLOCK FRICTION	17.169731
		REV CATCHUP COL	27.45396
		REV LAND E LOSS	120.095246
TOTAL LOSSES	214.258776	TOTAL LOSSES	457.176384

POSITION	BETA	ALPHA	EPSILON	PERIOD	BOOT
0	12.00000000E 01	47.24089500E 00	92.00056400E-01	0.30000000E-39	
1	42.57330000E 00	47.24089500E 00	92.00056400E-01	78.73974600E-04	-17.031440E 03
2	17.01064000E 00	50.60230000E 00	95.1662100E-01	14.60487300E-04	-17.7756500E 03
3	-10.668300000E 00	55.08831600E 02	39.01996900E-01	15.51234300E-04	-16.11129300E 03
4	-40.72832005 E 00	29.24930000E 00	14.77186700E-01	17.07997500E-04	-17.17663300E 03
5	-63.661767200 E 00	59.44821800E 00	-27.99933300E-01	99.99966200E-05	-15.8703140E 03
6	-11.39429333 E 01	59.44821800E 00	-27.99933300E-01	62.14500700E-04	0E.00000000E-41
7	-42.57732500E 00	59.44821800E 00	-27.99933300E-01	75.64259600E-04	16.0731100E 03
8	-17.01126300E 00	56.08710700E 00	-31.16494000E-01	14.75426700E-04	17.10549700E 03
9	78.791462001E-01	52.0513500E 00	-76.45776700E-01	13.92231200E-04	16.1285600E 03
10	40.72832005 E 00	47.43972400E 00	-96.77176900E-01	8.39037600E-04	17.29847500E 03
11	61.7014600E 00	47.24089500E 00	-16.79993300E 00	12.55449000E-04	15.9842100E 03
12	12.00000000E 01	47.24089500E 00	-16.79993300E 00	66.78924400E-04	0E.00000000E-43

EQUILY ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	3159.301514	TOTAL ENERGY	3159.301514
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	118.006567	FOR INPUT	366.559151
FOR IMPULSE	75.965338	REV JINPUT	366.559151
REV CATCHUP COL	93.245392		
REV IMPULSE	57.227259		
TOTAL GAINS	345.344552	TOTAL GAINS	733.110301
ENERGY LOSSES		ENERGY LOSSES	
FUR SIDE THRUST	91.098266	FOR SIDE THRUST	91.098266
FOR UNLOCK COL	21.934662	FOR UNLOCK COL	21.906662
FUR UNLOCK FRICTION	27.533010	FOR UNLOCK FRICTION	27.533010
FUR LAND E LOSS	35.291201	FOR CATCHUP COL	51.005602
REV SIDE THRUST	91.099266	FOR L AND E LOSS	165.746559
REV UNLOCK COL	20.349253	REV SIDE THRUST	91.098266
REV UNLOCK FRICTION	27.533010	REV UNLOCK COL	20.04253
REV L AND E LOSS	30.735892	REV UNLOCK FRICTION	27.533010
		REV CATCHUP COL	43.829865
		REV LAND E LOSS	193.326669
TOTAL LOSSES	345.344548	TOTAL LOSSES	733.110248

POSITION	BETA	ALPHA	EPSILON	PERIOD	DDOT
0	15.00000000E+01	47.24089500E+00	92.0006664000E-01	83.38023500E-04	0.00000000E-39
1	42.57733000E+00	47.24089500E+00	92.0006664000E-01	11.4967110E-04	-21.6742000E+03
2	17.01064000E+00	50.60207700E+00	95.1662610000E-01	12.1817720E-04	-22.39510900E+03
3	-10.32791500E+00	39.36454300E+00	39.64543000E-01	-22.61654900E+03	
4	-40.702832000E+00	59.24230000E+00	14.7718670000E-01	13.55937450E-05	-22.23078500E+03
5	-64.16278500E+00	59.4421892E+00	-27.99933000E-01	7.4614760E-05	-21.1997100E+03
6	-14.40476800E+01	59.46821800E+00	69.86632490E-04	0.11110000E-43	
7	-42.57712600E+01	59.46821800E+00	-27.99933000E-01	60.5193910E-04	21.43912500E+03
8	-17.01063000E+00	26.08710100E+00	-31.15474300E-01	1.1.5573770E-04	-22.34976400E+03
9	76.11728300E+01	52.09692490E+00	-76.03765500E-01	10.95089520E-06	24.79926300E+03
10	40.70283200E+00	47.43973430E+00	-94.77186900E-01	14.6387480E-05	21.25229300E+03
11	62.35874400E+02	47.24089500E+00	-14.79993300E+00	98.90277300E-05	21.25229300E+03
12	15.00000000E+01	47.24089500E+00	-14.79993300E+00	73.08553500E-04	0.11110000E-43

EQUIL. ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	6192.231018	TOTAL ENERGY	6192.231018
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	216.749573	FOR INPUT	736.800148
FOR IMPULSE	155.939180	REV INPUT	736.800148
REV CATCHUP COL	186.090698		
REV IMPULSE	117.209575		
TOTAL GAINS	645.989021	TOTAL GAINS	1473.60296
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	180.754997	FOR SIDE THRUST	180.754997
FOR UNLOCK COL	44.775876	FOR UNLOCK COL	44.775876
FOR UNLOCK FRICTION	55.342572	FOR UNLOCK FRICTION	55.342572
FOR L AND E LOSS	13.941694	FOR CATCHUP COL	100.932930
REV SIDE THRUST	180.754997	REV SIDE THRUST	180.754997
REV UNLOCK COL	42.246307	REV UNLOCK COL	42.246307
REV UNLOCK FRICTION	55.342572	REV UNLOCK COL	42.246307
REV L AND F LOSS	52.830063	REV UNLOCK FRICTION	55.342572
REV CATCHUP COL	87.246357	REV CATCHUP COL	87.246357
REV L AND E LOSS	389.646751	REV CATCHUP COL	87.246357
TOTAL LOSSES	195.389120	TOTAL LOSSES	1473.602911

POSITION	BETA	3H ₁	EPSILON	PERIOD	800T
0	21.00000000E+01	47.24095300E+00	92.003566500E-01	92.003566500E-01	0.0000000E+00
1	42.57733000E+00	47.24089500E+00	92.00066300E-01	86.8614000E-01	-31.5918810E-03
2	17.01106400E+01	50.60207300E+00	95.1662100E-01	80.86126730E-01	-31.6130650E-03
3	-10.03900100E+01	54.98114000E+00	62.1591200E-01	85.51269520E-01	-32.0426100E-03
4	-40.10283200E+01	59.24380000E+00	14.7186700E-01	96.11836350E-01	-32.0875250E-03
5	-64.56836500E+00	59.46821800E+00	-27.993300E-01	55.053176200E-01	-31.3426100E-03
6	-20.42329100E+01	59.44821800E+00	-27.993300E-01	78.44336250E-01	0E+0000000E+00
7	-42.57732600E+00	59.44421800E+00	-27.993300E-01	86.527887700E-01	31.28399100E-03
8	-17.31106322E+00	56.08116700E+00	-31.15446300E-01	80.94997200E-01	31.63065600E-03
9	73.86152460E+01	52.13163500E+00	-75.68236650E-01	76.93526500E-01	32.12715100E-03
10	40.10283200E+00	7.43913400E+00	-94.77186500E-01	1C.99673200E-01	32.16857200E-03
11	92.82699120E+00	7.26895200E+00	-14.79993100E+00	69.622556200E-01	31.52175200E-03
12	21.00000000E+01	47.24389500E+00	-14.79993000E+00	80.81615900E-01	0C.00000000E+00

EJ104 ESCAPEMENT ENERGY BALANCE		TOTAL SYSTEM ENERGY BALANCE	
TOTAL ENERGY	10236.136719	TOTAL ENERGY	12236.136719
ENERGY GAINS		ENERGY GAINS	
FOR CATCHUP COL	394.964966	FOR INPUT	1222.752960
FOR IMPULSE	263.129601	REV INPUT	1232.752960
REV CATCHUP COL	310.441528		
REV IMPULSE	197.579012		
TOTAL GAINS	1166.39498	TOTAL GAINS	2455.505920
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST	303.939550	FOR SIDE THRUST	300.839550
FOR UNLOCK COL	75.270226	FOR UNLOCK COL	75.270226
FOR UNLOCK FRICTION	92.594654	FOR UNLOCK FRICTION	92.594654
FOR L AND S LOSS	126.219226	FOR CATCHUP COL	157.812927
REV SIDE THRUST	300.939550	FOR L AND E LOSS	565.605461
REV UNLOCK COL	72.115091	REV SIDE THRUST	300.839550
REV UNLOCK FRICTION	92.594634	REV UNLOCK COL	72.115091
REV L AND S LOSS	105.523955	REV UNLOCK FRICTION	92.594654
REV CATCHUP COL	145.409714	REV CATCHUP COL	145.409714
REV L AND E LOSS	652.42356	REV E LOSS	652.42356
TOTAL LOSSES	1166.394989	TOTAL LOSSES	2455.505829

POSITION	BETA	ALPHA	EPSILON	PERIOD	BOOT
0	27.0000000E-01	47.24089500E-00	92.0056400E-01	91.30161630E-01	0.0000000E-39
1	42.5773300E-01	47.24089500E-00	92.00566630E-01	91.30161630E-01	-45.63276330E-03
2	17.0110400E-00	50.60202700E-00	95.1026100E-01	62.45310200E-05	-46.81689200E-03
3	99.21987000E-01	54.96822230E-00	40.38371400E-01	65.98093880E-05	-41.3720100E-03
4	-44C-70282200E-00	59.24921800E-00	14.771885700E-01	76.67579500E-05	-51.75798730E-03
5	664.72599600E-01	59.444921800E-00	-27.99933360E-01	42.47463330E-05	-41.19757300E-03
6	-226.4423600E-01	59.444821800E-00	-27.99933360E-01	63.17629100E-04	CC..CCCCOCDC-45
7	-442.5773600E-01	29.446821800E-00	-27.99933360E-01	69.77650400E-04	46.77198230E-03
8	-117.01156100E-01	56.38716700E-00	-31.15444500E-01	62.41374100E-05	46.68476500E-03
9	72.95263000E-01	52.146643900E-00	-75.518891500E-01	59.382911200E-05	41.42391500E-03
10	45.70253200E-00	47.42973400E-00	-94.7716900E-01	80.805594200E-05	41.78209300E-03
11	63.5125200E-01	47.24089520E-00	-14.79933300E-01	53.78356500E-05	41.12694320E-03
12	26.999999900E-01	47.24089530E-00	-14.79933300E-01	65.01253200E-05	00.0000000E-05

EQUILIBRIUM ENERGY BALANCE

TOTAL ENERGY 15291.219287

ENERGY GAINS

FOR CATCHUP COL

FOR IMPULSE

REV CATCHUP COL

REV IMPULSE

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR LAND E LOSS

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV LAND E LOSS

TOTAL GAINS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

FOR LAND E LOSS

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL GAINS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

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REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

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REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

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FOR UNLOCK FRICTION

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REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

ENERGY LOSSES

FOR SIDE THRUST

FOR UNLOCK COL

FOR UNLOCK FRICTION

FOR CATCHUP COL

REV SIDE THRUST

REV UNLOCK COL

REV UNLOCK FRICTION

REV CATCHUP COL

REV LAND E LOSS

TOTAL LOSSES

TOTAL ENERGY		TOTAL SYSTEM ENERGY BALANCE	
ENERGY GAINS		TOTAL ENERGY 15291.019287	
FOR CATCHUP COL		ENERGY GAINS	
393.263062		FOR INPUT 1854.4111C2	
397.466146		REV INPUT 1854.4111C2	
456.455781			
REV IMPULSE			
298.331753			
TOTAL GAINS 1755.359726		TOTAL GAINS 3758.822205	
ENERGY LOSSES		ENERGY LOSSES	
FOR SIDE THRUST 451.351917		FOR SIDE THRUST 451.351917	
FOR UNLOCK COL 113.389516		FOR UNLOCK COL 113.389516	
FOR UNLOCK FRICTION 139.288626		FOR UNLOCK FRICTION 139.288626	
FOR LAND E LOSS 191.224387		FOR LAND E LOSS 191.224387	
REV SIDE THRUST 451.351917		REV SIDE THRUST 451.351917	
REV UNLOCK COL 109.555425		REV UNLOCK COL 109.555425	
REV UNLOCK FRICTION 139.288626		REV UNLOCK FRICTION 139.288626	
REV LAND E LOSS 159.109571		REV LAND E LOSS 159.109571	
TOTAL LOSSES 1755.359940		TOTAL LOSSES 3758.822235	
POSITION		PERIOD	
BETA		Epsilon	
PHI		800T	
0		0.00000000E+01	
1		42.573320E-01	
2		17.3196430E-01	
3		-28.6298520E-01	
4		-9.7076320E-01	
5		-64.805330E-01	
6		-42.5773260E-01	
7		-17.01106100E-01	
8		72.49499720E-01	
9		-2.15388990E-01	
10		47.437973400E-01	
11		63.12382700E-01	
12		32.94999900E-01	
0		47.24089500E-01	
1		56.08710100E-01	
2		-75.45665100E-01	
3		-94.77186935E-01	
4		-16.79993300E-01	
5		-14.79993300E-01	
6		-27.99933300E-01	
7		91.81693500E-01	
8		-31.15494200E-01	
9		-50.88271200E-01	
10		68.37741300E-01	
11		65.8181371100E-01	
12		50.61554200E-01	
0		87.65781500E-01	
1		-5.0.0192881E-03	
2		-50.0.0935330E-05	
3		53.7424100E-05	
4		-40.4919800E-05	
5		60.78229170E-05	
6		-31.3548670E-05	
7		34.5936720E-05	
8		-27.99933300E-01	

AMPLITUDE Dyne/cm	APPLIED TORQUE Dyne-cm	PERIOD SEC	BEAT RATE BEATS/SEC		BEAT RATE ERROR PERCENT(REF.1)
			40.13528700E-03	49.83146100E-03	
60.0000000E-00	22.67447100E-01	40.13528700E-03	49.83146100E-03	-46.388941300E-02	
75.0000000E-00	38.49180100E-01	39.95401700E-03	50.05754400E-03	-12.303886900E-03	
90.0000000E-00	56.38294100E-01	39.90033500E-03	50.12464100E-03	12.171973300E-02	
12.022222E-01	10.91428400E-02	39.88555220E-03	50.16359500E-03	15.95790300E-02	
15.032222E-01	17.50191000E-02	39.84964200E-03	50.12928300E-03	13.09949600E-02	
21.022222E-01	35.17961500E-02	39.92380000E-03	50.09604800E-03	64.67790300E-03	
27.032222E-01	58.05961700E-02	39.94216000E-03	50.07195800E-03	16.48796000E-03	
31.052222E-01	88.14160820E-02	39.95569120E-03	50.05527100E-03	-17.24335000E-03	

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Harry Diamond Laboratories Washington, D. C. 20438	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
2b. GROUP		
3. REPORT TITLE SOME THEORETICAL NOTES ON THE DETACHED-LEVER ESCAPEMENT		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (First name, middle initial, last name) David R. Haley		
6. REPORT DATE December 1968	7a. TOTAL NO. OF PAGES 126	7b. NO. OF REPS 3
8a. CONTRACT OR GRANT NO.	8b. ORIGINATOR'S REPORT NUMBER(S) TR-1421	
8c. PROJECT NO. DA-1T061102B33A 8d. AMCMIS Code: 5011.11.85800 8e. HDL Proj. No. 48000	8f. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT Distribution of this document is unlimited		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Army Materiel Command	
13. ABSTRACT This report presents a continuation of the first detailed mathematical analysis made on a detached-lever escapement timing device. The model studied was based on the TSEL pin-lever escapement, designed primarily for ordnance applications. Although good quantitative results evolved from the original study, subsequent work suggested that the model was not capable of simulating certain characteristics of the detached-lever escapement. For example, this type escapement often had a torque sensitivity characteristic (frequency vs driving torque) that was concave upward. Further mathematical analysis has resulted in minor but apparently significant changes to the original model, indicating the feasibility of predicting the performance of an escapement more accurately. Also, this analysis—though probably incomplete—now indicates that certain basic characteristics of timers can be changed without changing the basic mechanism.		

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Detached lever escapement	8	3				
Torque sensitivity	7	3				
Mechanical timer	8	3				